

AN INVESTIGATION OF THE CHARACTERISTICS
OF SMALL, GAS FIRED RAKU KILNS

by

RAYMOND KAHMEYER 265

B. A., Kansas State University, 1963

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

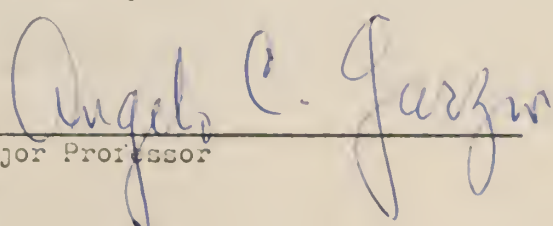
MASTER OF ARTS

Department of Art

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1968

Approved by:


Major Professor

ACKNOWLEDGMENTS

Special acknowledgment is tendered to Professor Angelo C. Garzio who, in addition to serving as my major professor, offered direction and support far above the norm, and, in the process, acquainted me with the pleasures inherent in clay.

For their assistance and encouragement, Mr. John Hannah, Associate Professor of Art; Mrs. Opal B. Hill, Associate Professor of Art; Mr. Oscar V. Larmer, Associate Professor of Art and Head of the Art Department; and Mr. Elmer Tomasch, Associate Professor of Art are to be thanked.

Also, I acknowledge the aid given in photography and typing by my sister, Miss Joy Kahmeyer.

TABLE OF CONTENTS

Chapter	Page
INTRODUCTION	1
HISTORY OF TEA, ZEN-BUDDHISM AND RAKU.	12
RAKU IN AMERICA.	31
RESEARCH MATERIALS	35
Bricks.	35
Fuel.	38
Fuel Delivery Components.	38
Burner Parts.	39
Temperature Measuring Device	45
Raku Clay Bodies.	45
Raku Glazes	48
Design Criteria	49
KILN DESIGN, EXPERIMENTATION AND PROCEDURES.	51
Initial Updraft Kiln Design and Firing Experimentation.	51
Revised Construction and Firing Experiments of Updraft Kiln Designs	54
Downdraft Kiln Design and Firing Procedures	74
SUMMARY OF THE FIRINGS	92
THESIS POTTERY	100
BIBLIOGRAPHY	119
APPENDIX.	121

INTRODUCTION

The past few years have seen an interest in Raku pottery develop and grow in this country. This is due, in large measure, to the efforts of several leading potters such as Kenneth Ferguson, Angelo Garzio, Paul Soldner, and Hal Riegger, who, through their studio work, publications, demonstrations and workshops, have exerted a considerable influence on many potters, students, and lay people. The recent interest in Raku is probably also related to the inclusion of that kind of pottery in some of the major crafts exhibitions held of late in this country. The 1966 Decorative Arts and Ceramic Exhibition at Wichita, Kansas accepted twelve Raku articles, and the Syracuse Ceramic National, 1967, displayed fourteen Raku pieces. Articles dealing with the technical and philosophical aspects of the medium have appeared with some frequency in the foremost crafts publications. The influential nature of these factors, coupled with the ease, excitement, and quickness of the medium is almost certain to appeal to a larger circle of professional and part time potters, some of whom will undoubtedly seek information regarding proper kilns and firing procedures.

Raku ware was first produced in Japan in the sixteenth century for use in a ceremony of tea which symbolized a way of life when the tea and pottery were considered by the Zen-Buddhists to be helpful in achieving ultimate enlightenment through contemplation and introspection carried out in surroundings attuned to nature. The character of the ceremony, as well as the taste of the tea master, required that the ritual pottery possess certain fundamental characteristics: one of them being the freely formed, subtly asymmetrical, and totally unobtrusive form of the tea bowl. The aesthetic also demanded the same spontaneity in the glazes and firing.

It was the potential of Raku for quick, free expression that initially

attracted the men listed above to the medium. While variations exist from potter to potter in terms of technique and approach, there are several factors common to most. The clay must be of a coarse, open nature in order for the finished pot to withstand the rigors of the kiln. Porosity is achieved by adding *grog* (particles of fired clay) in amounts up to one-third to a plastic clay such as fireclay or stoneware. This mixture retains the essential plasticity of clay while possessing coarseness and porosity necessary for the firing. (Plate I, Fig. 1). After the pots have been formed and dried, they are given a preliminary firing to harden the clay. After glaze has been applied, they are placed with tongs in the incandescent chamber of a kiln and left until approximately 1750°F. is reached. When the glaze is seen to be fully melted, the pot is withdrawn (Plate I, Fig. 2), placed in a container of combustible material (Plate II, Fig. 1) where it is enveloped by the dense smoke (Plate II, Fig. 2) which promotes the reduction of metallic oxides in the glaze which, in turn, enriches glaze color. After a short period of smoking, the piece is submerged in water (Plate III) where the thermal shock tends to promote the crackle pattern seen on the finished pot in Plate IV.

While the study was undertaken primarily for the purpose of identifying some of the characteristics of small, gas-fired kilns of such size and design as to be serviceable in the Raku process, the writer felt that, inasmuch as tea and Zen-Buddhism contributed so heavily to the origin and evolution of Raku, a summary of their histories could be informative and helpful to one interested in the current American application of Japanese Raku. Consequently, included in the thesis is a chapter surveying the history of tea, Zen (including its predecessors, Buddhism and Confucianism), and Raku, seeking to show how these three constituents of Oriental culture fused in the tea ceremony of sixteenth century Japan.

EXPLANATION OF PLATE I

- Figure 1. Coarse, grogged clay is required for the making of Raku ware. While grainy and open, the clay is plastic and lends itself to the freely done forms often associated with the Raku process.
- Figure 2. During the firing, the condition of the glaze can be observed through a small observation port provided in a wall of the kiln. When the glaze is seen to be thoroughly melted, the pot is removed with iron tongs.

PLATE I



Figure 1



Figure 2

EXPLANATION OF PLATE II

- Figure 1. The pot is taken from the kiln with the glaze still molten and quickly placed in a container of sawdust.
- Figure 2. Coming directly from the kiln, the pot is hot enough to ignite the sawdust. During the period of intense smoking following ignition of the sawdust, the chemistry between carbon in the smoke and oxygen in the glaze occurs. The combination of carbon and oxygen leaves the metallic oxides of the glaze in an altered form and has the effect of enriching the colors.

PLATE II



Figure 1



Figure 2

EXPLANATION OF PLATE III

- Figure 1. When the pot is taken from the sawdust it is in a blackened condition due to the concentration of carbon surrounding it during the burning. At this point, carbon and oxygen are still combining.
- Figure 2. In order to terminate the chemistry between carbon and oxygen, and to render the color permanent, the pot is plunged into water. The rapid cooling sometimes has the additional effect of causing the glaze to develop an interesting network of cracks known as crazing.

PLATE III



Figure 1



Figure 2

EXPLANATION OF PLATE IV

The finished pot as it appears after the excess carbon has been scrubbed away. The crazed pattern was emphasized by a second smoking which allowed carbon to enter and darken the cracks. The crazing is only through the glaze and the clay itself is not affected by the cracking.

PLATE IV



The primary concern of the thesis was small, gas-fired kiln design. The criteria which were established before the research commenced were tailored to the particular demands of Raku firing and were used as standards by which the kilns were judged. The four test kilns were evaluated on the bases of the temperature achieved after ninety minutes of firing, the average temperature gain per five minute period, and the average temperature lost per kiln opening. The kilns were also compared in terms of their abilities to recover glaze melting temperature after each opening.

Inasmuch as temperature and general performance exceeded Raku requirements, it seems reasonable to assume that the kilns, particularly the two having larger volumes, could be serviceable in firing other kinds of pottery. If the proper bricks were used, and if the designs were modified slightly, the writer feels certain that the kilns could be utilized for salt-glazing pottery, thus expanding their utility to the studio potter.

In assessing the problem, attention is drawn to the summation of data as given in Table 2 in the Summary of the Firings. Based upon the performance factors listed there, and upon the way in which the kilns have functioned during many firings held subsequent to the conclusion of the research, an assertion that the problem was successfully concluded seems justified.

HISTORY OF TEA, ZEN-BUDDHISM AND RAKU

"Pots, like all other forms of art, are human expressions: pleasure, pain, or indifference before them depends upon their natures, and their natures are inevitably projections of the minds of their creators."¹ Historically, Raku pottery is so inextricably bound up with "the minds of their creators" that any attempt to survey the history of this delightful way of producing pottery must include some understanding of the social and intellectual forces acting on the minds of the Raku potters. Because a great deal of what was in the "minds of their creators" manifested itself in a ceremony using tea, this survey must also include an account of the evolution of tea as a beverage.

The tea plant is said to be native to southern China and known from "very early times to Chinese botany and medicine."² It was not only sought after for the medicinal benefits it was thought to provide, but also for its supposed mystical qualities of "delighting the soul, strengthening the will. . ."³ At first, because it was rare and expensive, tea was a beverage available to only the aristocracy. Rulers, on occasion, gave it as a reward to court officials for outstanding service. By 500 A.D., tea was in favor as a beverage in the Yangtse-Kiang Valley of central China. "Yet the method of drinking tea at this stage was primitive in the extreme. The leaves were steamed, crushed in a mortar, made into a cake, and boiled together with rice, ginger, salt, orange peel, spices, milk, and sometimes onions!"⁴

¹Bernard Leach, A Potter's Book, 1949, p. 13.

²kakuzo Okakuro, The Book of Tea, 1964, p. 11.

³Ibid. p. 11.

⁴Ibid. p. 11.

The arrival of the T'ang Period (618-906) in China brought "one of the great periods of world art."⁵ With it came the first devotee of tea; one Lu Wu, a poet. He lived in the eighth century when Buddhism, Taoism, and Confucianism were seeking mutual synthesis. In his work Ch'a Ching (The Holy Scripture of Tea) the "Code of Tea" was set forth. Ch'a Ching consists of three volumes and is a treatise of all the aspects of tea, from the nature of the plant through the preparation and serving of the liquid. Lu Wu was, as a result of Ch'a Ching, recognized by the Emperor T'ai Tsung (763-779), thus assuring him a fame which attracted many followers, and which was sufficiently strong to establish the tea ceremony as a quasi-religious rite, although it remained for Japan, some 800 years later to raise the ceremony to its highest level of expression.

Lu Wu's Ch'a Ching, which established standards for the equipment and vessels required for tea storage, preparation, and service, had an immediate influence on Chinese ceramics. As the "Code of Tea" gained disciples, there was an accompanying demand for pottery to prepare and serve tea according to the code. Lu Wu preferred a blue glazed porcelain bowl made in southern China because the blue strengthened the greenish cast of the tea.

As the T'ang period gave way to the Sung era (960-1280), there was a shift in preference from cake-tea to powdered tea. The tea leaves were dried, then ground in a small stone mortar and pestle. When prepared for serving, the powder was whipped in hot water with a specially made bamboo brush; then, Okakura says, served to guests in heavy, dark brown or blue black bowls.⁶ Writing in The Book of Pottery and Porcelain, Warren Cox describes the various types of porcelain and stoneware tea bowls produced by the Sung potters. Many

⁵Warren E. Cox, The Book of Pottery and Porcelain, 1966, p. 104.

⁶Okakura, op. cit. pp. 12,13.

of them have the dark colored glazes mentioned by Okakura. The influence of the tea cult in terms of pottery production, in quality as well as quantity, is quite apparent as Cox describes and illustrates tea vessels from many of the Chinese provinces. The Sung potters achieved a high level ceramics despite the fact that . . . "during this time there was internal conflict, intrigue, and constant threats from the North which finally ended in conquest and flight."⁷

The conquest of Sung China was accomplished by the Mongol Yuan Emperors in 1280.⁸ Okakura states that the Mongols . . . "destroyed all the fruits of the Sung culture," and although the Yuan era endured less than a century (1280-1368), it was, according to Okakura, long enough to destroy many of the refined "manners and customs" of tea practiced in Sung times.⁹ When Chinese nationalism re-emerged under the Ming Dynasty, the dried tea leaves were prepared by steeping them in hot water and the beverage was served in light, thin, white-glazed porcelain bowls. For the Ming Chinese, drinking tea was more a ritual than a ceremony with the deep meaning of former T'ang and Sung times. Okakura says that "To the latter-day Chinese, tea is a delicious beverage, but not an ideal."¹⁰

While the importance of ceremonial tea was waning in China, it was growing ever stronger in Japan. Tea was known in Japan as early as 729 A.D., probably introduced in leaf form by ambassadors returning from the T'ang court. This tea was prepared and served in much the same way as in T'ang China. Cox

⁷Cox, op. cit., p. 130.

⁸Ibid., p. 420.

⁹Okakura, op. cit., p. 16.

¹⁰Ibid., p. 16

says that nothing of importance so far as pottery is concerned occurred during this time in Japan. Hazel Gorham writes in Japanese and Oriental Pottery that during all the time that the tea ceremony was practiced . . . "bowls from widely different sources have given pleasure to many."¹¹ Given this dearth of locally produced pottery suitable for tea drinking, and the predilection for using "bowls from widely different sources," one concludes that no great significance was attached to a particular pottery type for use in the tea ceremony. Sung tea reached Japan in 1191 in seed form; was widely planted, thus assuring an ample supply to meet the increasing demands for the leaves as the tea ceremony came to be more and more a part of her culture. Tea, at this time in Japan was dispensed in the Sung manner; that is, it was prepared as a powder and combined with hot water by beating the mixture with a bamboo whisk. Unlike the casual attitude toward the tea ceremony vessels which seems to have prevailed during the earlier cake-tea period, the tea masters of the powdered variety had definite qualifications for the tea bowls. Gorham states that the dark, Temmoku glazed bowls of China were "priceless" to the Japanese teaists. She further states that a white Korean ware called Hakuji was also "admired by many." By the fifteenth century, the tea ceremony was well established in Japan. During the seventeenth century, the Ming variety of steeped tea was introduced and largely replaced the earlier powdered variety except for certain occasions; though the latter continued to be the standard of excellence.

The tea ceremony has continued as a strong cultural force in Japan through the centuries. The influence which cha no yu, as the ceremony of tea had come to be called, on Japanese ceramics was considerable; culminating in the

¹¹ Hazel Gorham, Japanese and Oriental Pottery, p. 33.

sixteenth and seventeenth centuries with a new approach to pottery making. The product of this new approach was given the name Raku and it was fostered by Zen Buddhist ideals.

In terms of influence on the tea ceremony and on Raku pottery, Zen Buddhism played a vital role. However, before Zen began to emerge as a significant cultural force during the Tang period, there had been a long struggle with Confucianism, Taoism and Buddhism for supremacy.

Confucius, Lao Tse, and Gotama, founders of Confucianism, Taoism and Buddhism were all born within a fifty-year period circa 600 B.C. The three cults developed concurrently; the former two within the Chinese state, the latter in what is now India, later spreading to China, where, as Swann says, it achieved . . . "victory over Confucianism" in post Han times.¹²

Confucius was born in 551 B.C. in Northern China in the province of Lu, into a family of humble means. Perhaps because of his low birth he acquired a life-long sympathy for the common people who suffered much under the oppressive measures of the feudal lords who held sway during the chaotic period following the breakup of the Chou dynasty. As he observed the excesses and abuses of the rulers, he concluded that:

. . . government should be administered for the benefit of the whole people. And he reached the conclusion (which has been fundamental to Confucianism ever since) that no sovereign formula, however glittering, could guarantee this. This goal, he believed, could only be reached if the government were continuously administered by men of the highest personal integrity, trained for government service and so devoted to the cause of the public welfare that they would die, if necessary, rather than betray it.¹³

Confucius sought a government position from which his views could be promulgated but soon left in disgust. He died in 479 B.C., seemingly having failed to alter

¹²Peter Swann, Art of China, Korea, and Japan, p. 61.

¹³Herbert Creel, Confucius and the Chinese Way, p. 29.

the Chinese way. Of the consequences of Confucius' life, Creel says: ". . . Few human lives have influenced history more profoundly If we look for the secret of his appeal, it seems probable that it lies in his insistence upon the supremacy of human values."¹⁴

After the death of Confucius, his disciples promulgated his teachings so effectively that in the second century B.C. Confucianism was made the state cult in preference to Taoism (which had grown concurrently with Confucianism) because the latter was generally regarded to be too quietistic and negative. Acceptance of Confucianism as the "state cult" had, according to Swann's interpretation of the events, far reaching and long lasting effects upon the arts of the Han dynasty.¹⁵ The Confucian concept that only the most enlightened men should rule led to the practice of submitting all prospective civil servants to a rigorous examination including a broad area of the arts. Swann feels that this practice led Han art to the relatively high levels which it reached during the four hundred years that the dynasty endured.

The teachings of Confucius offered no definite concept of life after death to the Chinese people. On the other hand, the form of Buddhism which reached China included a promise of existence beyond death. Perhaps this is the feature of the alien religion that, attractive as it must have been to the Chinese struggling under the oppression of their conquerors from the north, enabled it to eventually supplant the indigenous doctrine of Confucius.

Writing of the life of Buddha, whose family name was Gotama (sometimes Guatama), Richard Gard says: "His dates are still problematical . . . most Western scholars date the Buddha variously ca. 566-486 (the preferable

¹⁴ibid. p. 45.

¹⁵Swann, op. cit., p. 36.

date), 563-483, or 558-478 B.C."¹⁶

Fundamentally, Buddha held that ignorance is the cause of all suffering and that in order to alleviate misery and hardship, one must attempt to reach Nirvana, ". . . which is a condition or state of mind of complete peace."¹⁷ He proposed that Nirvana could best be attained by mastering oneself in terms of self enlightenment. However, the ultimate enlightenment could not be attained, nor could Nirvana be reached, in one lifetime. Therefore, it became necessary for the life and death cycle to be repeated many times before one could know Nirvana, and the enlightenment that transcends life's problems. In this way, Buddha hoped that a new order of peace would be brought to the world, bringing with it a supreme enlightenment to the practitioners.

After Buddha's death in 483 B.C., his disciples slowly spread his teachings over a large area of northeast India. Entering China in the first century A.D. Buddhism broke up into various sects which stressed one aspect or another of the faith. During the years between the time of the Han collapse (220 A.D.) and the beginning of the T'ang period (618 A.D.), the various sects struggled for ascendancy not only against each other but against Taoism and Confucianism. "The victory of the Buddhist faith" cited by Swann was the outcome of the struggle.¹⁸ Again, quoting Swann: ". . . generally speaking, this was the great age of Buddhism. The faith reached a height of influence and artistic inspiration which it never again achieved."¹⁹ The reincarnation concept inherent in Buddhism at first was odious to the Chinese, committed as they

¹⁶ Richard Gard, Buddhism, p. 59.

¹⁷ Swann, op. cit., p. 61.

¹⁸ ibid. p. 61.

¹⁹ ibid. p. 98.

were to ancestor worship. However, the objection was slowly overcome by the ascendancy of the Mahayana sect which held that, while lives filled with humane goodness might eventually entitle one to enter the extinction of Nirvana, one was prevented from actually entering (thus causing ancestors to become extinct) in order for infinite repetition of the life-death-life cycle to bring more good qualities into the world. The "height of influence and artistic inspiration" endured into Ming times when it was imported by Japan in the form of Zen. Commenting on the impact of Buddhism on Chinese art, Laurence Binyon in The Spirit of Man in Asian Art says:

Above all, there is a perfect fusion of the sensuous and the spiritual. The spiritual significance of life is not emphasized so as to become disdainful . . . ; it is . . . something which unites and does not divide. This natural poise and harmony seem to be the active power which animates the glowing scenes, making what are called aesthetic necessities appear as almost irrelevant externality. The color is deep and ardent. . . ." ²⁰

These years of Buddhist supremacy were the years during which powdered, whipped tea was in vogue; the time when, as Okakura says, ". . . tea began to be not a poetical pastime, but one of the methods of self-realization." ²¹ Under Zen, tea was actually to become one of the most important ways to achieve "self-realization."

The growth of Zen, said by Swann to have been introduced into China late in the T'ang period, was so inter-connected with native Taoism that they practically developed together. ²² Lao Tzu, author of Tao Teh Ching (King), from which Taoism sprang, was born in 604 B.C. Tao Teh Ching (Tao Teh King), which translates to "The way of the Universe," advocated desirelessness and

²⁰ Laurence Binyon, The Spirit of Man in Asian Art, p. 48.

²¹ Okakura, op. cit., p. 15.

²² Swann, op. cit., p. 150.

non-agitation; discredited all man-made criteria; and held that an unassertive and effortless behavior, ". . . accomplishes much more than blustering, violent effort." The severity of these teachings was lessened by Lao Tzu's successors to the extent that, when Taoism met Zen in the tenth century, it had enough in common with Zen-Buddhism to make a merger imminent. Binyon summarizes Taoist doctrine at this time as:

Man is set in a world of beauty diversified with terror. His spirit goes out to explore it. He is ever seeking to come to terms with the world outside himself, to attain some sort of harmony with the living and vast energies which pervade it, or at least some understanding of them. He may return upon himself, persuaded that all the varied beauty of the material world is an illusion, and that only within the mind is secure reality to be sought. . . . It lifts the human soul into an atmosphere where earthly cares are transcended rather than refused.²⁴

Zen originated in India as one of the many sects which developed after the Buddha's death in 483 B.C. It was brought to China in 520 A.D. by the famous Bodhidharma where he founded C'han (later to be called Zen) Buddhism.²⁵ This new concept of Buddhism took root in the south of China. There, under the auspices of several consecutive emperors, the new religion flourished. Zen, like Buddhism had as its ultimate goal a state of ultimate enlightenment which was called Satori. While the two concepts had similar ends in view, they differed greatly in the means employed to reach the final state. The Buddhist was to reach Nirvana by living a useful life each time that life was regenerated. For the Zenist, however, Satori could be acquired quite suddenly by allowing the intellect to be completely transcended. Zen doctrine held that while the intellect was useful in the application of knowledge; it was only through the

²³ Jack Finegan, The Archaeology of World Religions. pp. 382-54.

²⁴ Binyon, op. cit., pp. 74, 76.

²⁵ William Willets, Chinese Art, Vol. II, p. 616.

senses and intuition that true knowledge could be acquired. Zen teachers made use of various tactics to enable the novitiate's intellect to be supplanted. One such device was a rapid question and answer exchange between master and pupil which accelerated the latter's thought processes to the point where his conscious intellect failed and was transcended by the senses and intuition. Other strategies were employed, but always the intent was to displace the conscious mind, thus liberating the sub-conscious to receive pure knowledge. A favorite practice of the Zen Masters was to place a pupil in a natural setting, questioning him about the realities of nature. This was said to be an effective means of achieving sudden enlightenment--Satori.²⁶

The subjective nature of Zen, permitting as it did, an individualistic approach to his life, and standing in such sharp contrast to the objective features of the earlier Buddhism, appealed, as Swann says, ". . . to both intellectual and non-intellectual. . . ." ²⁷ The similarities of Taoism and Zen were such that a fusion of the two was inevitable. Of this conjunction Fenollosa writes:

It was then that Taoism joined hands with the budding Zen to enforce individuality. . . . If we could get a concrete picture of the seething, the individualistic poetic China of this day, say from 1060 to 1126--less than the normal life of a man--we should witness ²⁸ the greatest illumination of the whole east, the whole Asiatic world. . . .

The same writer assesses the magnitude of this shift in Chinese thought in this way: "This revolution in Chinese feeling, and in art, was, however, a great one . . . for it implied no less a change in Buddhist and in social contemplation than the substitution of the natural for the supernatural. If I call it idealistic contemplation, it is because it regards nature as more than a jumble

²⁶Humphreys, op. cit., pp. 182-185.

²⁷Swann, op. cit., p. 150.

²⁸Ernest F. Fenollosa, Epochs of Chinese Art, Vol. II, pp. 2, 19.

of fortuitous facts, rather as a storehouse of spiritual laws. It thus becomes a great school of poetic interpretation.²⁹

The first manifestation of this new national freedom of thought is noted in the supremacy of individual life and art during the period (960-1280 A.D.) of the Sung dynasty. In Cox's opinion, the

. . . pure and simple taste of the Sung period had reached the pinnacle of perfection in China and perhaps the whole world. I believe, and others agree with me, that the finest vases and bowls ever made in the world were made then.³⁰

Eminence was achieved by all the arts--not only pottery. Describing the art of this period in Art of China, Korea, and Japan, Swann frequently uses such adjectives as peaceful, introspective, refined, subtle, discreet, sensitive, delicate, gentle. These all seem to repeat what the creative output of the Sung artists embodied: a feeling for the mysteries of nature. Swann also records that the Sung ". . . were swept away by the most devastating of all the barbarian invaders--the Mongols."³¹

In this way, art and life in China evolved, reached the high point, and passed into a decline from which it never recovered. After a hundred years of domination by the foreign Yuan emperors, the native Mings were able to once again unite the nation and bring to it a semblance of stability. Okakura and others have written that, despite worthy accomplishments in some areas, Ming art is, if not decadent, for the most part inferior when compared to the Sung. They seem overly concerned with technique, flamboyance, and color. Not even Zen which had sparked the greatness of the Sung era could provide impetus for

²⁹ Ibid., p. 1.

³⁰ Cox, op. cit., p. 442.

³¹ Swann, op. cit., p. 141.

the Chinese to regain, much less surpass, the work of the previous times.

While Zen may not have been able to generate a renaissance in China, it did not perish there and cease to be, ". . . the most aesthetic of all Buddhist creeds. . . , which holds man and nature to be two parallel sets of characteristic forms between which perfect sympathy prevails."³² Events of Chinese history and subsequently, the history of Japan, seem to suggest that, while China accepted and nourished the alien teachings of Buddha, making them intrinsically her own in the form of Zen, this long period was but a prelude to what awaited Zen in Japan.

After Buddhism's supremacy during the post-Han era, it swept on to the northeast until it entered Korea about 372 A.D., where it flourished for several centuries before being subdued by a Confucian reaction. It was from Korea, during the years of Buddhist dominance, that the religion was exported in 552 A.D. across the narrow sea to Japan. After a few years of resistance from Shinto cults, the regent Shotoku (593-622) embraced the religion and became a devout patron. Although his life was short, he established Buddhism widely and effectively by building many temples and shrines, by importing artist-craftsmen from Korea and China; and by building a large Buddhist monastery.³³ Writing about this period of Japanese history, Hugo Munsterberg is quite emphatic about the impact of Buddhism on her art: "For the development of Japanese ceramics, as for practically every other aspect of Japanese culture, the decisive turning point came in 552 A.D. when Buddhist emissaries from Korea reached Japan."³⁴

³²Fenollosa, op. cit. p. 4.

³³Humphreys, op. cit., pp. 69-70.

³⁴Hugo Munsterberg, The Ceramic Art of Japan, p. 85.

The Nara, Heian, and Fujiwara (late Heian) periods (646-1185) experienced not only the continued growth of Buddhism, but also an influx of T'ang and Sung art from China—and with it, came Zen. It is said that during the ensuing Kamakura era (1185-1333) Zen influence on Japanese art and life was confined primarily to the Zen temples.³⁵ However, in the succeeding reign of the Muromachi (1334-1573) Zen came into its own and literally swept a cultural renaissance across the country. Warren Cox, writing in The Book of Pottery and Porcelain emphasizes the influence: "Now, a hundred years after the Sung period was through and done with, its influence became dominant in Japan and . . . the . . . period is looked upon as a sort of Sung Renaissance."³⁶

Without exception, literature surveyed pertinent to this period of Japan's history indicated that in order to understand the culture of the times, one must also understand cha no yu—the Japanese Tea Ceremony. Several writers also suggested that, for a non-Oriental—and more particularly, for a non-Japanese—a complete understanding is virtually impossible. Whatever understanding of the ceremony is to be had must come through Zen, for as Okakura said: "The whole Ideal of Teaism is a result of the Zen conception of greatness in the smallest incidents of life."³⁷

Yoshimitsu, the first of the Muromachi shoguns, accepted Zen with a missionary-like zeal and rapidly imported a vast quantity of Sung pottery and painting, which quickly spread Zen and Zen-inspired work across Japan. This strategy was employed by Yoshimitsu in an attempt to rescue Japanese society from the disintegration which it was then experiencing. It was during this

³⁵Penollosa, op. cit., p. 64.

³⁶Cox, op. cit., p. 232.

³⁷Okakura, op. cit., p. 29.

time that Zen came to mean "Liberation and Enlightenment."³⁸ It was a concept of minimums and utmost simplicity, and held that only by achieving complete rapport with his surroundings could one hope to become fully enlightened. This rapport could best be developed by meditation and study of the minute aspects of the environment; ostentation was avoided because it clouded the mind; nature was venerated for it signified the reality of things; great truths could be gleaned from small things, because, in the total scheme of things, a grain of sand was as significant as a mountain. The Japanese sought to symbolize all these aspects of Zen in their cha no yu.

Binyon observes that the Tea Ceremony was first held by Soami, a painter living in the fifteenth century. The ceremony was conducted with restrained taste in a room carefully proportioned and austere furnished. At this time, the ceremony was held in a specially prepared room of a dwelling. In the sixteenth century, Rikyu, whom Okakura says, is the greatest of all tea-masters, instituted an independent tea-room removed from the dwelling. This was done in order to provide a setting more conducive to the meditative nature of the ceremony. Tea-room architecture was severe and pure in the manner of Zen monasteries.

The ceremony itself is deceptively simple in appearance. Munsterberg relates a description of the ceremony which Rikyu is said to have given:

. . . in characteristic Zen fashion: "You place the charcoal so that the water boils properly, and you make the tea to bring out the proper taste. You arrange the flowers as they appear when they are growing. In summer³⁹ you suggest coolness and in winter coziness. There is no other secret."

In practice, the ceremony was somewhat more complicated. Guests, usually a small number, were invited by the Tea-master. The tea-room was often remotely

³⁸Binyon, op. cit., p. 164.

³⁹Munsterberg, op. cit., p. 100.

placed and was approached by walking over a specially prepared path (known as a roji) to conform with the forthcoming cha no yu. Okakura interpreted the function of the roji: It ". . . was intended to break connection with the outside world, and to produce a fresh sensation conducive to the full enjoyment of aestheticism in the tea room itself."⁴⁰ Rikyu claimed that the aesthetic qualities of a properly prepared roji were to be found in this verse:

I look beyond;
Flowers are not,
Nor tinted leaves,
On the sea beach
A solitary cottage stands
In the waning light
Of an autumn eve.⁴¹

Once reached, all the guests enter the tea-room through a door only three feet high; this, to introduce a humble feeling in preparation for the ceremony. Inside, except for the gentle noise of boiling water, all is quiet and remains so until the host appears. Working quietly and deliberately, he prepares tea for one guest at a time by adding hot water to a small amount of powdered tea. Then the mixture is stirred vigorously with a slender stalk of bamboo frayed at one end. Having drunk, the guest carefully examines the bowl, compliments the owner, and returns it. The bowl is washed and the next guest is served. After all the guests have been served, the articles of the tea service are offered for their inspection and comments. This is followed by a quiet discussion or by a period of meditation, after which the guests silently depart, each supposedly enriched by the experience. To suggest that the ceremony of tea is "charming" or that it somehow is similar to Christian church ritual is to utterly miss the significance of it, and to introduce the very meaning which

⁴⁰ Okakura, op. cit., p. 34.

⁴¹ Ibid. p. 36.

the Teaists sought to delete. Commenting on the broad culture of this time (culture which gave rise to the Tea Ceremony), Binyon has written:

This art is the reflection of a period which has no parallel elsewhere in history. The Japanese propensity to carry things to extremity is seen in an attempt to order life by a purely aesthetic ideal. If beauty, they seem to say, is the most precious thing in the world, let us believe in it, let us take it for our star and guide, and go to the very end. Never was devotee more exacting with himself, never was moralist more exacting with other people, in the pursuit of the right. But it was not right belief or right conduct that was the standard; it was right taste. Art dominated life.⁴²

This attitude that life should be dominated by art made possible the development of a pottery type which the Tea-masters found to be most characteristic of cha no yu.

It must be emphasized that the influence of the masters of tea (chajin, as they came to be called) over aesthetic matters was considerable. Munsterberg describes their influence in this way, ". . . the taste of the Tea-masters has continued to exert a powerful influence on Japanese culture."⁴³ Of the chajin influence on Japanese ceramics, Okakura states:

Our pottery would probably never have attained its high quality of excellence if the Tea-masters had not lent to it their inspiration, the manufacture of the utensils used in the Tea-ceremony calling forth the utmost expenditure of ingenuity on the part of our ceramists.⁴⁴

Rikyu, early in his role as a chajin, preferred to serve tea in simple rice bowls used by Korean peasants; valuing them for their quiet utility in the tea ceremony. Also in demand were the temmoku glazed bowls from China. However, the widespread acceptance of cha no yu created such a shortage of imported tea wares that Japanese potters began to make tea bowls and other articles of the tea service.

⁴²Binyon, op. cit., p. 155.

⁴³Munsterberg, op. cit., p. 100.

⁴⁴Okakura, op. cit., p. 62.

Rikyu gave added impetus to this Japanese ceramic movement by patronizing the potter Chojiro with a commission for tea bowls to be used in his tea ceremonies. Under Rikyu's auspices, Chojiro's work gained eminence, and after his death, the emperor Toyotomi Hideyoshi presented a golden seal to Chojiro's son Jokai in memory of his father's work. Carved into the seal was the character raku (meaning pleasure) which was taken from Jurakudai, the name of Hideyoshi's palace where Chojiro had worked. Whether or not Hideyoshi intended it, his grant of the seal established a line of Raku potters, all stamping their ware with the character Raku, which continues, as Leach says, to the present day. The line was continued by Donyu, whose work, according to Munsterberg, constitutes in the eyes of Japanese critics, the high point of Raku. Donyu was followed by Koetsu. Donyu's grandson Kuchu continued the Raku tradition into the eighteenth century, after which the Raku line of pottery is said to have gone into a decline.⁴⁵

Criteria by which Raku was judged for tea use are found in the concepts of wabi. According to Munsterberg, the meaning of wabi ranges from "peaceful, simple, rustic," to "subdued—a spirit of restraint."⁴⁶ The wabi cult was instituted by Rikyu to express the standards by which he felt one should live. Much emphasis was placed on a serene existence devoid of all ostentation and self-regard. The concept that man was a small, but integral, part of nature was to be conveyed to the individual by surrounding him with articles having features that were subtle and restrained. Surroundings of this type were felt to be conducive to the contemplation needed to achieve empathy with nature—and from nature, the ultimate enlightenment of man's true role in the universe.

⁴⁵ Munsterberg, op. cit., pp. 99-107.

⁴⁶ id., p. 100.

To the Tea-masters Raku incorporated all the restraint that the wabi cult required. Tea bowls were, for the most part, quickly made by pinching the form from a ball of coarse clay. The underside was usually given a base by carving a footring into the soft clay with a piece of sharpened bamboo. The finished forms displayed the directness and quickness of the method which formed them. Depressions left by the pinching fingers and marks made by the bamboo were retained as being expressive of the forming method. The forms were often subtly asymmetric with uneven rims. Also used in the tea ceremony were bowls and storage jars made on the potter's wheel. These forms express the same unassuming characteristics as the hand-made pots. After a preliminary firing to harden the clay, the forms were glazed with a thick glaze, dried, placed in a kiln and heated to red heat. The glaze was freely, almost carelessly, applied. Interesting subtly of color and texture was often the result. The glaze firing was consistent with the overall spirit of spontaneity. Leach described in The Potter's Book, his first encounter with the method of firing Raku in Japan shortly after the turn of this century:

Presently, a number of unglazed pots were brought in and we were invited to write or paint upon them. I struggled with the unfamiliar paints and the queer long brushes, and then my two pots were taken from me and dipped in a tub of creamy white lead glaze and set around the top of the kiln and warmed and dried for a few minutes before being carefully placed with long-handled tongs in the inner box or muffle. Although this chamber was already at a dull red heat the pots did not break. Fireclay covers were placed on top of the kiln, and the potter fanned the fuel until the sparks flew. In about half an hour the muffle gradually became bright red, and the glaze on our pots could be seen through the spy hole melted and glossy. The covers were removed and the glowing pieces taken out one by one and placed on tiles, while the glow slowly faded and the true colors came out accompanied by curious sharp ticks and tings as the crackle began to form in the cooling, shrinking glaze.

A number of "schools" evolved from the rather solitary beginnings of Raku pottery making. Among them were the Seto, notable for subtle color and

⁴⁷Leach, op. cit., p. 30.

elephant designs; the Shino with forms of very coarse clay covered with a thick, creamy white glaze over or under which had been painted abstracted designs from nature; the Oribe which utilized bold designs and a green glaze often covering only a portion of the form; the Bizen, usually unglazed, and relying on the color richness of bare, fired clay; and the Iga and Shigarki, both of which emphasize crude irregular qualities of clay and form.

With the decline of these schools, the vigor of the entire Raku movement began to disappear; and it, as many movements before and since, succumbed to the perils of over exposure, progress, and the chronological tendency for one school of art to be succeeded by another. However, the philosophies and techniques inherent in the medium were destined to reappear at another time in another place.

RAKU IN AMERICA

The Japanese culture which fostered Raku developed, with the exception of influences from Korea and China, independently of outside stimulus, and largely unknown to Americans prior to the nineteenth century.

Japan was opened to English, Spanish and Portuguese traders and missionaries early in the seventeenth century during the Tokugawa period. However, the Spanish, in an over-zealous missionary effort, caused the Japanese rulers to suspect that their country was being prepared for overthrow, and the Europeans were summarily deported. Accompanying the expulsion of all foreigners was a decree from the shogun, Iemitsu, forbidding any citizen to leave the country. The decree also closed Japan to all outside contact except that a small amount of trade was to be allowed with the Dutch through the port of Deshima. This policy of extreme isolationism was steadily maintained until, under the threat of Perry's naval force at Yokahama in 1854, Japan was finally opened to the Western nations.⁴⁸

Infusion of Japanese culture into this country was at first slow. Gifts of lacquer ware, porcelain and costumes presented to Perry were received with little enthusiasm when shown in this country upon his return. The first broad look that Americans had at Japanese art came in 1876 when the Japanese government contributed architecture, pottery and sculpture to the Centennial International Exhibition of that year in Philadelphia. The first response to the Japanese collection seems to have been an architectural one with quasi-Japanese tea houses appearing in the gardens of some American residences.⁴⁹

⁴⁸Marius B. Jansen, "Japan History," Encyclopedia Britannica, 1966, Vol. 12, pp. 902-903.

⁴⁹Clay Lancaster, The Japanese Influence in America.

Clay Lancaster describes the period following the Exhibition: "Within a decade after the Philadelphia Centennial the Japanese vogue had achieved a firm toehold in the eastern United States."⁵⁰ This "toehold" was strengthened by Japanese participation in the World's Columbian Exposition at Chicago in 1893, and in the California Midwinter Exposition of 1894.

Japan's influence on the minor arts, or at least in the appreciation of the minor arts, was felt more slowly than her influence on architecture. Individuals, such as Edward Morse and Christopher Dresser assembled, and presented to museums, large collections of Japanese pottery. During the first part of this century, the Japanese government opened bazaars in San Francisco, Boston and New York for the sale of handcrafted articles from Japan. Coming before the American people at a time when they were preoccupied with art nouveau and the classic revivals, the Japanese things presented a strong contrast. Potteries in Ohio and in Massachusetts were started, both turning out pots based upon the Japanese forms.

In 1903 Kakuzo Okakura arrived in Boston from Japan where he had been regarded as a foremost aesthetician. He became Curator of Chinese and Japanese Art at the Boston Museum of Fine Arts in 1911. During his short tenure, "The Oriental collections . . . became world famous, and it has been said that with Okakura the study of Oriental art attained its first maturity."⁵¹ Okakura, as he traveled and lectured in this country, did much to promote public awareness of Japanese art.

The influence of Japanese art grew slowly, but steadily, through the first half of this century. Interrupted during the war years of the 1930's

⁵⁰ ibid. p. 62.

⁵¹ Okakura, op. cit., p. xi.

and 40's, it re-emerged at mid century to contribute to contemporary work because, ". . . the free and easy manner of the Japanese goes hand in glove with the modern movement stressing self-expression."⁵²

In 1940, Bernard Leach's A Potter's Book was published in America. This book, giving an account of the author's extensive stay in Japan, placed emphasis and focused attention upon Japanese pottery, including Raku. The book was widely accepted by potters, and provided some of them, for the first time, with a source of technical and aesthetic information relative to Raku.

Perhaps another major step was taken in the direction of Raku in the late 1950's when the influential potter, Peter Voulkos, reacted to the symmetry of wheel-made pottery and began to work with freely-done sculptural forms. Voulkos and some of his students literally changed the course of much of American ceramics, and, in the opinion of the writer, did much to prepare the way for the advent of Raku in this country.

Paul Soldner, then a California potter, began to work in a modified Raku manner during the first part of the 1960's. He was an early spokesman for the Raku process, and through his efforts Raku has been broadly accepted by contemporary potters.

Early in 1965, in a review of the 1964 Syracuse Ceramic National, written for Crafts Horizons, Daniel Rhodes said:

Raku pots are shown by Paul Soldner (California), Virginia Curtwright (New York), Joe Soldate (California), Hal Riegger (California), Noah Alonso (Michigan), and others. These pieces form almost a class of pottery by themselves. Their unpredictable surfaces and wayward forms add a pleasant note of contrast. Nothing would amaze a Japanese Raku potter more, however, than the sight of these Syracuse pieces. Our Raku style is home grown. . . ."⁵³

⁵² Lancaster, op. cit. p. 230.

⁵³ Daniel Rhodes, "Ceramic National," Crafts Horizons, (January, February,) XXV, No. 1. 16-23.

Another indication of the viable state of American Raku came with the publication of Angelo Garzio's Raku portfolio in Ceramics Monthly in 1967. Writing of his own approach to Raku, Garzio said: "Raku is a symbolic connotation of the way I feel and react toward clay as a material It is a catalyst and a catharsis of myself as a human being and of my reaction to my fellow man."⁵⁴ Speaking of the Raku movement in general, Garzio said:

It is to the credit of American potters . . . that they are utilizing both the philosophical and technical aspects of the traditional Japanese potters by greatly enlarging and enhancing the scope and magnitude of this approach An understanding of raku provides a means of enriching the aesthetic life experiences of these potters that is far more effective than an attempt merely to produce imitations of tea bowls. . . . But we now find a great variation in the form and size of the pottery, from large-bodied closed forms and low platters or bowl shapes, to combinations of raku and other natural materials such as stumps or branches; surface textures and colors are broadened in scope by the use of stains or engobes, used alone or under or over a glaze. . . . This then is one of man's most noble gestures in his reaching out and intuitively leaping into the unknown to resuscitate a vestige of his potential for relating himself to the universal spirit of the Beautiful. This is raku in its most profound aspects."⁵⁵

⁵⁴ Angelo Garzio, "Raku." Ceramics Monthly, Vol. 15, No. 6, (June, 1967), 19-26.

⁵⁵ Ibid., p. 21.

RESEARCH MATERIALS

Bricks

Dense Firebricks. With the exception of the dense firebricks, material and equipment were chosen for their ability to perform to certain specifications. Dense firebricks, having load-bearing qualities that the soft insulating firebricks do not have, were used to construct a base for each kiln. (Plate V, Fig. 1) They also provided a heat barrier to protect the concrete slab on which all the kilns were built. The bricks measure $2\frac{1}{2} \times 4\frac{1}{2} \times 9$ inches.

Insulating Firebricks. Each kiln was constructed of the insulating firebricks (Plate V, Fig. 2) on a dense firebrick base. These insulating bricks have the same dimensions as the dense firebricks ($2\frac{1}{2} \times 4\frac{1}{2} \times 9$), and though very fragile, they have a much greater heat retaining quality and are therefore better suited for kiln construction than are the dense types. The type of insulating bricks chosen for this series of kilns was "G-23" as manufactured by the A. P. Green Firebrick Company of Mexico, Missouri. The 23 of the "G-23" indicates that the bricks are designed to withstand temperatures up to 2300° Fahrenheit. The manufacturer has this to say of the "G-23" insulating firebricks:

These lower temperature insulating bricks are composed entirely of highest quality materials and possess the three most desirable properties of insulating firebrick: high insulating value, structural strength, and the ability to withstand high temperatures without shrinkage. They are recommended for service in direct contact with flame and furnace gases in furnaces heated with gas, oil, powdered coal and electricity.⁵⁶

Although the manufacturer ascribes to the bricks the property of "structural strength," the term is a relative one and the impression should not be left that this type firebrick has great resistance to compression forces which would develop in a large, heavy, kiln. The "high insulating value" mentioned above

⁵⁶A. P. Green, Refractory Pocket Catalog, p. 34.

EXPLANATION OF PLATE V

- Figure 1. Dense firebricks of the standard $2\frac{1}{2} \times 4\frac{1}{2} \times 9$ size were used as bases for all the research kilns. These bricks have a dense structure, making them suitable for the loadbearing position at the base of the kilns.
- Figure 2. Unlike the brick illustrated in Figure 1, the insulating firebrick shown here is light and porous, having as its primary function the retention of heat. Its dimensions are the same as those for the dense type.

PLATE V

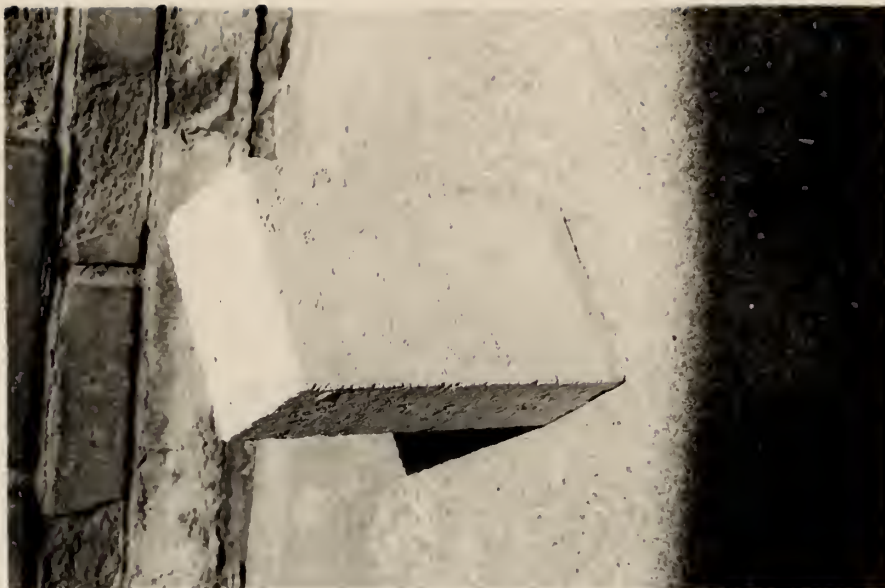


Figure 1



Figure 2

is said by the manufacturer to derive from the process of production.

They are made from uniform sized, multi-cellular lightweight aggregate having a strong, ribbed internal structure--resulting in extra high strength and low density. They are produced without the aid of artificial burn-out materials, thus they have an extremely uniform internal pore structure . . . free of large voids and free of internal cracking caused by the usual burn-out materials.⁵⁷

Under actual firing conditions when the internal kiln temperature reached 2000° F., the exterior surface was only slightly warm. Despite an occasionally cracked brick and a tendency for small particles to be abraded from the surfaces by normal handling, it was felt that the bricks were well suited to the needs of the problem.

Fuel

Each kiln tested was fired using commercial propane gas purchased from a local supplier. Propane is a liquefied gas which is kept in the liquid state under pressure of 200 lbs. per square inch at 60° Fahrenheit. The gas is supplied in metal cylinders equipped with a release valve located on top. When this valve is opened, and the internal pressure is released, the propane is changed from the liquid to the gaseous state. The properties of propane vary widely according to the manufacturer. The gas used in these experiments has a specific gravity of .508 and yields 3,000 BTU per cubic foot. The BTU rating can be given another way: One gallon of liquid propane yields 32 cubic feet of gaseous propane; therefore, one gallon yields 96,000 BTU's.⁵⁸

Fuel Delivery Components

In order to supply gas to the burner, it is led from the cylinder release valve through a pressure regulator and pressure gauge to neoprene hose

⁵⁷Ibid., p. 33.

⁵⁸Data supplied by the Tri-county Gas Company, Manhattan, Kansas.

equipped with appropriate fittings which, in turn carries it to the burner where the gas is mixed with air, producing a long tapering flame. Because the pressure inside the propane cylinder varies according to the external air temperature (the internal pressure increases or decreases respectively) and causes a flame of varying length and intensity, a pressure regulator was installed atop the cylinder in order to stabilize the flow of gas to the burner. The regulator is fitted with one inlet and three outlets. A pipe fitting connects the propane cylinder to the regulator at the inlet side of the regulator. Two of the three outlets are used as burner supply lines. The pressure gauge is inserted in the third outlet. All three outlets are subject to the stabilized pressure after the gas has moved through the regulating diaphragm of the pressure regulator. Pressure to the burners is controlled by turning the adjusting screw on the face of the regulator. Each supply line is made independent of the other by the use of globe-type valves. (Plate VI, Fig. 1) Specifications of the supply hose are as follows: Gates Type 2013 3220A, Butane Propane Hose, MH5761 3/8 in., 350 MAX. WP 2 BRD, 1750 Burst, LPG, Manufactured by the Gates Rubber Company. Because of the relatively high pressures involved, all connecting fittings between the cylinder and pressure regulators, regulator and hoses, hoses and burners are made of brass and are of the flare type which depends upon a tight metal to metal contact to prevent leakage. Gasket materials are said to be subject to decomposing action of the propane.

Burner Parts

The burners employed were of the atmospheric type as manufactured by the Eclipse Fuel Engineering Company of Rockford, Illinois. The burner is composed of an injector and burner nozzle. The injector is Eclipse T-40 with a 5/64" orifice. The orifice is adjustable. "Atmospheric burners are so called because they use air at atmospheric pressure, thus requiring no blowers or air

EXPLANATION OF PLATE VI

- Figure 1. By equipping the propane cylinder with two globe type valves, in addition to the pressure regulator and pressure indicating gauge, it was possible to fire two burners simultaneously while using only one cylinder of propane.
- Figure 2. This sectional view of the injector part of the eclipse atmospheric burner used to fire the kilns identifies the various components.

PLATE VI

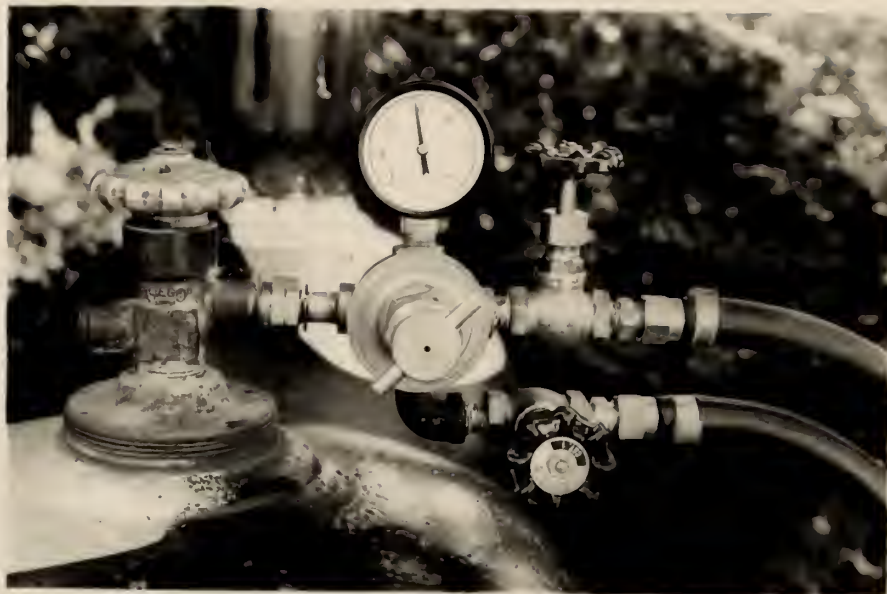


Figure 1

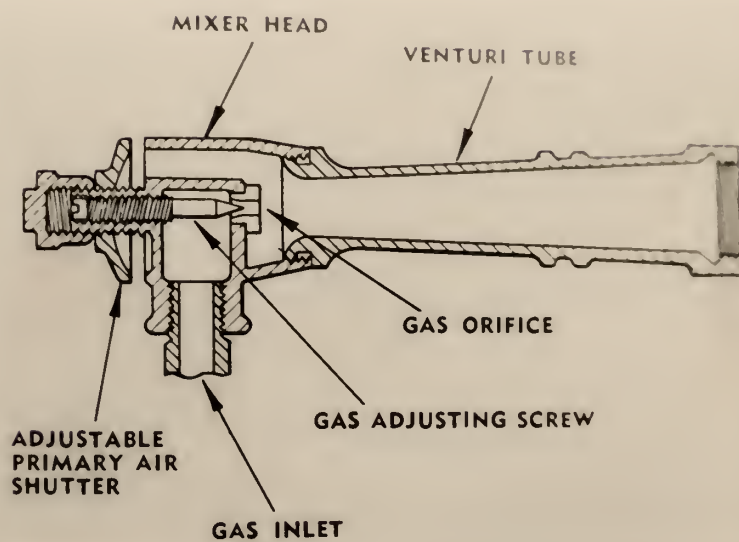


Figure 2

compressors. They are the most frequently used type of gas burning equipment . . . due to their comparatively low cost, ease of adjustment, and lack of maintenance."⁵⁹ Gas passes through the orifice in the mixer head. (See Plate VI, Figure 2 for injector nomenclature, and Plate VII, Figure 1 for a view of the injector). "As this expanding gas enters the throat of the venturi tube it creates a suction which draws in air through the adjustable air shutter. The energy of the gas stream forces the gas-air mixture into the burner. . . . The air drawn in through the venturi throat is called 'primary air' and that supplied around the flames is 'secondary air.'"⁶⁰ Varying the pressure of the propane being supplied to the burner influenced the length and heat intensity of the flame. Closing or opening the "adjustable primary air shutter" made the flame respectively more or less oxidizing. The adjustable orifice proved to be a helpful feature of the burner in that it provided an auxiliary method of controlling the amount of gas delivered to the flame. Several types of burner nozzles (which produce a variety of flame shapes and intensities) are available for use with the T-40 injector. However, Eclipse 4F-Type 1 (Plate VII, Fig. 2) was chosen for these experiments because of the long tapered flame it was said to produce. It was designed to yield a maximum 100,000 BTU's per hour with six inches of water column mixture pressure, the mixture containing 80 per cent of the required air necessary for complete combustion.⁶¹ During the course of the experimentation, the burner was fired under many conditions and was shown to be flexible and reliable—flexible in application in terms of being able to sustain either a gentle, low temperature flame or four pounds gauge pressure or a long

⁵⁹Bulletin H-1. Eclipse Atmospheric Burners. p. 2.

⁶⁰Ibid. p. 2.

⁶¹Bulletin H-15, Eclipse Fuel Engineering Division. p. 3.

EXPLANATION OF PLATE VII

- Figure 1. The injector is shown with primary air control shutter at far left, high pressure hose connection at lower left, and burner nozzle socket at far right.
- Figure 2. The threaded end of the burner nozzle at left fits into the right end of the injector of Figure 1 to complete the atmospheric burner assembly.

PLATE VII



Figure 1



Figure 2

intense flame of 40 pounds gauge pressure, and reliable in that the quality of the flame did not vary when fired for a long period of time.

Temperature Measuring Device

In consultation with the major advisor, it was determined that a pyrometer should be used to measure kiln temperatures. The installation is shown in Plate VIII, Figure 1. Temperature was indicated on the gauge (upper left) by a needle which moved in response to electricity which was generated by heating the thermocouple (lower right) which protruded into the kiln interior. As the thermocouple came under increasing heat, the needle responded with a higher temperature reading. This system proved very helpful in observing kiln response to adjustments of gas, air and flue openings during the research firings.

Raku Clay Bodies

While experimentation with clay bodies suitable for Raku work was largely outside the scope of this investigation, some time was given for that purpose. Washed river sand, vermiculite, and commercial grog were all combined with a stoneware clay in varying ratios. The sand and vermiculite were passed through a 14-mesh sieve. The grog was A.P. Green "P-Grog" 6-2-1-M-110 with particle sizes ranging from approximately 15-20 mesh. In all, 12 separate mixes were tried combining clay with sand, clay with vermiculite, clay with grog, clay with sand and vermiculite, clay with vermiculite and grog; and clay with sand, vermiculite, and grog. In terms of plastic working characteristics, condition of the bisque ware, and ability to withstand the thermal shocks resulting from the glaze firing, no mixture was superior to the one containing one part grog with three parts clay. Several mixes were noticeably inferior. The combinations containing sand were fragile in the bisque state and were very slow to dry after glazing. Impurities which caused the fired glaze to flake off in spots after firing were apparently introduced with the sand. This was a frequent occurrence.

EXPLANATION OF PLATE VIII

- Figure 1. The pyrometer consisted of a thermocouple protruding into the kiln chamber, two wires to carry the electrical current generated by the heated thermocouple, and the temperature indicating dial which acted in response to the heated thermocouple inside the kiln.
- Figure 2. The first experimental updraft kiln was subject to an over reducing condition. Indications of the effects of this problem can be seen in the blackened condition of the cup atop the kiln as well as in the areas on the front wall of the kiln which were darkened by too much carbon present in the interior atmosphere.

PLATE VIII



Figure 1

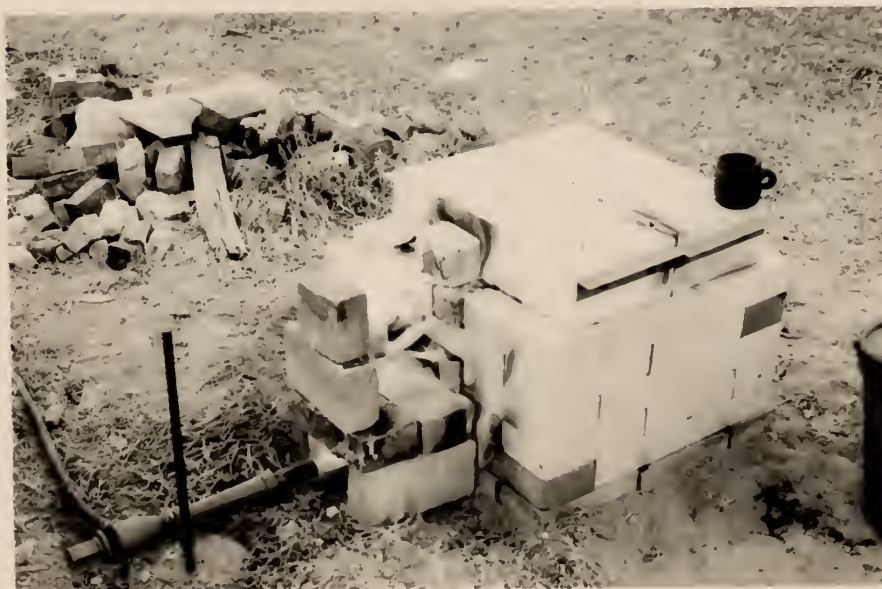


Figure 2

vermiculite caused such a close-grained and dense quality to develop that the majority of these pieces cracked either while firing or when taken from the kiln and exposed to the atmosphere.

Raku Glazes

As in the case of Raku clay bodies, the experimentation with Raku glazes was beyond the stated limits of the problem. However, it was felt that a variety of glazes with different melting temperatures could possibly reveal something of the kilns' efficiencies in terms of melting a variety of glazes. Temperature span of the glazes is from approximately 1750°F. (Number 1 listed below), to ca. 1840°F. for glaze Number 4. After the kiln designs had been refined, temperatures above the more refractory glazes were easily attained, and no difficulties were experienced in melting the glazes.

A second purpose in developing a limited palette of glazes was to enable the thesis pottery, which appears at the back of this paper, to exhibit a range of color and surface interest and to express a better union between form and glaze.

The following glazes were developed and used:

1. Semi-Transparent Off-White

Potassium Feldspar	62.5
Colemanite	37.5
Tin Oxide	2.0
Bentonite	2.0
2. Semi-Matte Opaque White

Potassium Feldspar	62.5
Colemanite	37.5
Tin Oxide	5.0
Bentonite	2.0
3. Semi-Gloss Copper Red to Blue to Green

Potassium Feldspar	50.0
Colemanite	30.0
Silica	20.0
Cobalt Carbonate	0.5
Copper Carbonate	1.5

4. <u>Semi-Matte Black</u>	
Potassium Feldspar	25.0
Colemanite	15.0
Silica	10.0
Albany slip	50.0
Cobalt Carbonate	2.5
Red Iron Oxide	5.0
5. <u>Semi-Matte Pale Blue</u>	
Potassium Feldspar	50.0
Colemanite	30.0
Silica	20.0
Cobalt Carbonate	0.5
Black Uranium Oxide	4.0

The glazes are designed to melt in the 1750°-1850°F. range, but were also tested at 2000°F. without displaying an excessively overfired quality.

Design Criteria

The following criteria were felt to be in keeping with the process of Raku pottery making and were used to evaluate the kilns' performances during the concluding segment of the problem.

Portability. Because the Raku process is best suited to an outdoor environment, it was felt that, if the kilns were entirely portable, they would be more serviceable. It was hoped that portability could be achieved by building the kilns with mortarless construction which would facilitate assembling and dismantling. Inasmuch as portability would also be a function of the fuel supply, it was decided to use only propane gas in moveable cylinders.

Accessibility of Materials. The writer felt that, if the kilns were to have practical application, the materials required for their construction and firing should be readily available at a reasonable cost. Consequently, all components were to be chosen from standard sources.

Firing Chamber Dimensions. In order to facilitate a rapid temperature rise, the chambers were not allowed to exceed two cubic feet. So as to preclude complicated assembling and dismantling procedures, plus minimizing

brick waste, all dimensions were to be based on $2\frac{1}{2}$ " x $4\frac{1}{2}$ " x 9" size of the standard firebrick. Thus, the horizontal dimensions were to be controlled by a $4\frac{1}{2}$ " module while a $2\frac{1}{2}$ " module was to govern vertical dimensions.

Firing Time. In the interest of efficiency, ninety minutes of firing time was to be allowed for the kilns to reach 1750° - 1800° F., the temperature range in which the glazes melt.

KILN DESIGN, EXPERIMENTATION AND PROCEDURES

Initial Updraft Kiln Design and Firing Experimentation

Several kiln loads of pottery were fired in an empirical manner for the purpose of equipment familiarization and establishing work procedures. These early firings were strictly of a preliminary nature and no effort was made to control the variables or measure the results.

The first kiln fired was an updraft (Plate VIII, Fig. 2) measuring $13\frac{1}{2}$ " wide x $13\frac{1}{2}$ " deep x $12\frac{1}{2}$ " high inside giving a volume of slightly more than 1.3 cubic feet.

Daniel Rhodes defines the updraft principle in this way:

In the updraft kiln, the fire enters the kiln at the bottom, passes upward through the ware chamber, and escapes from a flue at the top. . . . This design allows the hot gases to travel in the direction which they naturally take--upward. The updraft kiln has the advantage of simplicity of construction—it is essentially a box with openings for the burners at the bottom and a flue hole at the top. But this type of kiln has some serious disadvantages. For one thing, the heat of the fires striking directly on the props and lower shelves of the kiln causes them to deteriorate rapidly. But more serious is the tendency of the updraft kilns to be considerably hotter in the bottom than in the top.⁶²

Thus, an updraft kiln relies upon the natural upward movement of heated air to provide the needed circulation. As the heated air circulates through the kiln, it gives up heat to the interior and its contents.

Dense firebrick were used to construct the floor. The top was of insulating brick in two pieces, each section measuring 9" x 20" and held together by rods running through the bricks so as to provide the support required to span the kiln. This arrangement permitted one half of the top to be removed for ware removal while the other half remained in place thus helping to minimize the heat loss and subsequent temperature drop. It also made for easier handling

⁶²Daniel Rhodes, Clay and Glazes for the Potter, pp. 199-200.

of the lid when pots were inserted or removed from the kiln. In cross-section, the flue measured $2\frac{1}{2}$ " high by $9\frac{1}{2}$ " wide and was first placed at the top center of the back wall.

Initially, no use was made of a pressure regulator or pressure indicating gauge; the only means of controlling gas pressure to the burner being to close and open the discharge valve on the cylinder.

From the standpoint of efficient operation or accumulation of finished pottery, the initial firings were failures. However, in terms of knowledge gained deductively by observation and applied to later kilns, this preliminary series was worthwhile.

The most obvious shortcoming was the failure to reach a high enough temperature to melt the glaze. This was attributed to a heavy reducing flame. A reducing flame is defined as one containing unburned fuel—mostly carbon. When this condition prevails, not only does the excess carbon permeate the glaze and clay, but it represents lost heat which in turn precludes a significant temperature gain.⁶³

It was felt at this point that the burner flame needed more air to support complete combustion. Inasmuch as the primary air shutter was completely open, and because the literature supplied by the burner manufacturer indicated that the orifice, though adjustable, was pre-set for propane, an unbalanced air to gas ratio was not suspected as being responsible for the reducing quality of the flame. The factor suspected at this time was secondary air. To compensate, the burner which had been placed approximately $1\frac{1}{2}$ " from the fireport, was now moved back to 6", so that more air could be made available for combustion. The distance from burner tip to fireport was varied from $1\frac{1}{2}$ " to 12" without apparent

⁶³Daniel Rhodes, Stoneware and Porcelain: The Art of High Fired Pottery, pp. 152, 153.

benefit to the quality of the kiln atmosphere. Even if this had provided a solution to the problem it would have hardly been practical because of the susceptibility of the flame to being diverted by wind.

After it became apparent that an increase of secondary air did not lessen the reducing condition, the flame length was varied by increasing and decreasing the gas pressure to the burner. As the flame increased, so did reduction. When the pressure was decreased to the point where a gentle flame was produced, there was little, if any temperature increase. It was also noted that at the lower pressures the length of flame varied considerably although no valve adjustments were made. This led to the later use of a pressure regulator and a pressure indicating gauge. It will be shown later that the addition of these accessories was beneficial.

Another solution to the reducing problem was sought by varying the size, location, and number of flues. At one time, four openings, each measuring $2\frac{1}{2}$ " x $4\frac{1}{2}$ ", providing forty-five square inches of flue, were tried, one per wall. It was hoped that this would provide the necessary draft through the kiln interior and promote the needed temperature rise. This attempt also failed but before deciding to end this series of firings, one more attempt was made to correct the reducing problem.

It had been observed earlier that, despite the flames' constant contact with the floor bricks, they became red much more slowly than did the insulating bricks of the walls. In view of this disparity, the kiln was dismantled and the floor bricks replaced with insulating bricks; the theory being that, if the floor could be made to radiate heat, the draft might be increased. The kiln was rebuilt and fired. While there was a slight increase of temperature, the excessive reducing atmosphere was still present.

Conclusions drawn from the preliminary firings:

1. A pressure regulator would be needed to provide a steady flow of propane to the burner.
2. A pressure indicating gauge would be required in order to determine the kiln's responses to changing gas pressures.
3. In consultation with Professor Garzio, it was decided that there would have to be a design change which would allow a sufficiently strong draft to circulate through the kiln if the reducing problem was to be overcome.

Revised Construction and Firing Experiments of Updraft Kiln Designs.

The first kiln design tested under controlled conditions was based on the foregoing third conclusion. Whereas previously the flame entered the kiln just above floor level, in this version of the updraft principle, the flame is first introduced into a firebox located below the kiln and then into the kiln interior by passing through slits in the kiln floor. (Plate IX, Fig. 1) The interior, measuring 9" wide by 9" deep by 10" high, provided a volume of nearly one half cubic foot. The kiln cover and flue were combined in a single unit by bolting together four full-size bricks with a 1" shim in the center into which was cut a 1" x 4½" opening with the beveled surfaces as shown in Plate IX, Figure 2.

Adding the pressure regulator and gauge allowed control of pressures varying from 0 to 60 pounds per square inch (psi). This obviated the need for the pre-set condition of the burner orifice, and permitted its size to be regulated according to the pressure of the gas passing through it. With the pressure gauge reading 20 psi, the adjusting pin was turned until a blue flame with only a tinge of orange at the tip was produced. (Plate X, Fig. 1) Its length was approximately 22" and was judged by the color to be nearly oxidizing.

The kiln was fired for ninety minutes. Gas pressure was 20 psi and the flue remained completely open (i.e. 1" x 4½") throughout the ninety minute firing period. In ten minutes the pyrometer indicated 540°F., and after one half hour 1120°F. was recorded. However, there was a mild odor of raw propane

EXPLANATION OF PLATE IX

- Figure 1. The updraft kiln design was based upon the flame entering the firebox between the wedge-shaped pieces at the left. The flames entered the kiln chamber through the openings in the floor.
- Figure 2. A view of the bottom of the $4\frac{1}{2}$ " x 9" x 11" lid reveals how the flue opening was beveled to facilitate exit of the flames from the kiln.

PLATE IX



Figure 1



Figure 2

EXPLANATION OF PLATE X

- Figure 1. When propane was supplied to the burner at the rate of twenty pounds per square inch, a frequent firing pressure, a long, bushy flame resulted.
- Figure 2. At this point in the research, an over reducing atmosphere was common to the firings. The excessive reducing was characterized by an orange, smoky flame issuing from the flue.



Figure 1



Figure 2

EXPLANATION OF PLATE XI

- Figure 1. The blackened condition of the lid, bricks and pot testified to the intensity of the over reducing condition.
- Figure 2. A significant step was taken when the four bricks were added to the kiln lid. They formed a short chimney which served to increase the strength of the draft which pulled carbon from inside the kiln, thus solving the reducing problem.

PLATE XI

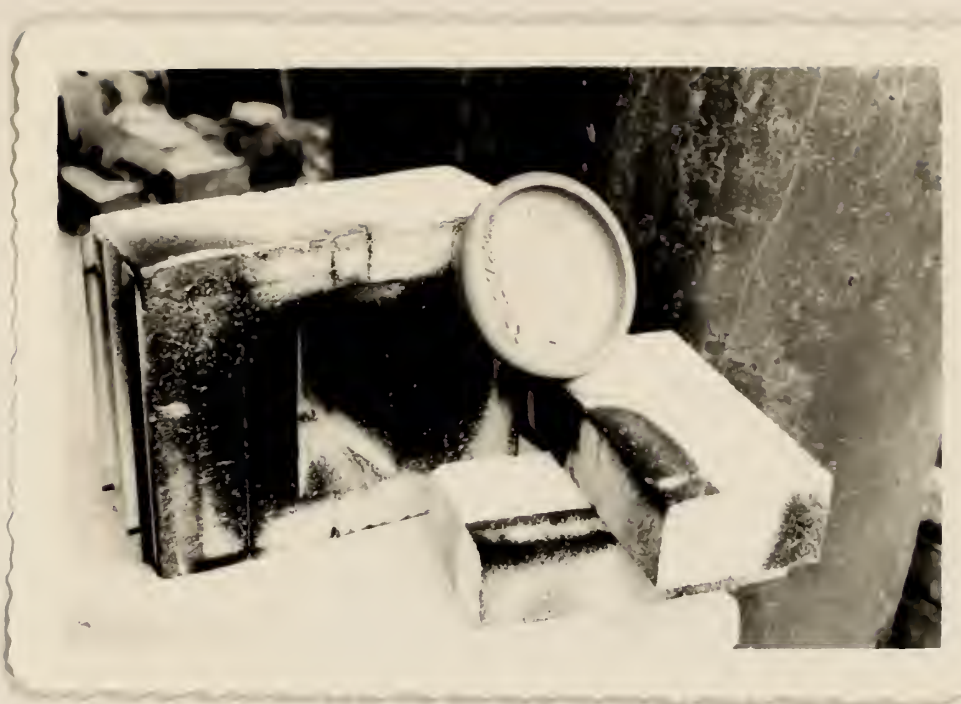


Figure 1



Figure 2

to had by increasing the gas pressure and the flue opening by a factor of three. The flue was increased to 3" x 4 $\frac{1}{2}$ " and the gas pressure changed to 20 psi. In ninety minutes, 1780°F. had been reached. The average temperature gain was 98.5°F. for each five minute interval. Again there were no adverse reducing effects noted. For the purpose of removing pottery, the cover was opened seven times for an average of 2.1 minutes during which an average of 146°F. were lost requiring an average of 21.5 minutes to recover.

These results led to the question of whether, since the only difference between the second and fourth tests was the flue size, the kiln efficiency could be further increased by strengthening the draft. Inasmuch as the cross sectional area of the flue represented nearly 17% ($13.5 \text{ in}^2 / 81 \text{ in}^2$) of the cross sectional area of the kiln it did not seem feasible to increase the cross-sectional area of the flue beyond that amount. In an effort to increase the draft, a short chimney consisting of four insulating bricks placed on end, was added to the top of the kiln lid. (Plate XI, Fig. 2). The chimney's cross section was the same as that of the flue: 3" x 4 $\frac{1}{2}$ ". Firing with this modification produced a temperature of 1880°F. in ninety minutes with an average temperature gain of 104.3°F/5 minute period. During the subsequent firings an average temperature decline of 132°F. occurred during the 34 cover openings, the average duration of which was 2.2 minutes. Average recovery time was 19.7 minutes. At this point in the program, it was felt that this kiln had developed sufficiently so as to satisfy the design criterion set forth at the beginning of the program. Table 1 summarizes the results of each variation in comparative form. Graph 1 is a composite of the rates at which the temperatures of each kiln rose.

The problem was continued in the form of another updraft kiln having dimensions 50% larger than the previous kiln. The measurements were 13 $\frac{1}{2}$ " x 13 $\frac{1}{2}$ " x 15", the volume being slightly more than 1.3 cubic feet. Features of

EXPLANATION OF TABLE 1

Basically, the information tabulated here does not differ, except in the form of presentation, from that given in Graph 1. The data indicates how, by lessening the gas pressure from 20 pounds used in kiln 1 to 6.6 pounds in kiln 2, a slight increase in final temperature was obtained. This temperature gain was interpreted as resulting from the diminished reducing atmosphere.

Attention was then given to decreasing the reduction further by increasing the draft. Widening the flue from 1" by $4\frac{1}{2}$ " as used in kiln 2, to 3" by $4\frac{1}{2}$ " when firing kiln 3 produced an increase of 80 degrees over the best temperature gotten from the former arrangement. Kiln 4 utilized the four brick chimney (Plate XI, Fig. 2) and provided enough draft to eliminate the reducing condition.

Table 1

Kiln	Temperature After 90 Minutes	Average Temperature Per 5 min. Period	Pounds of Gas Pressure Psi	Flue Size (Inches)	Average Time Lid Open (Minutes)	Average Degrees Lost	Average Recovery (Minutes)
1	1560°	87.7°	20	1 x 4 $\frac{1}{2}$			
2	1700°	94.5°	6.6	1 x 4 $\frac{1}{2}$			
3	1780°	98.8°	20	3 x 4 $\frac{1}{2}$	2.1	146°	21.5
4	1880°	104.3°	20	3 x 4 $\frac{1}{2}$ *	2.2	132°	19.7

*With chimney added (3" x 4 $\frac{1}{2}$ " x 9")

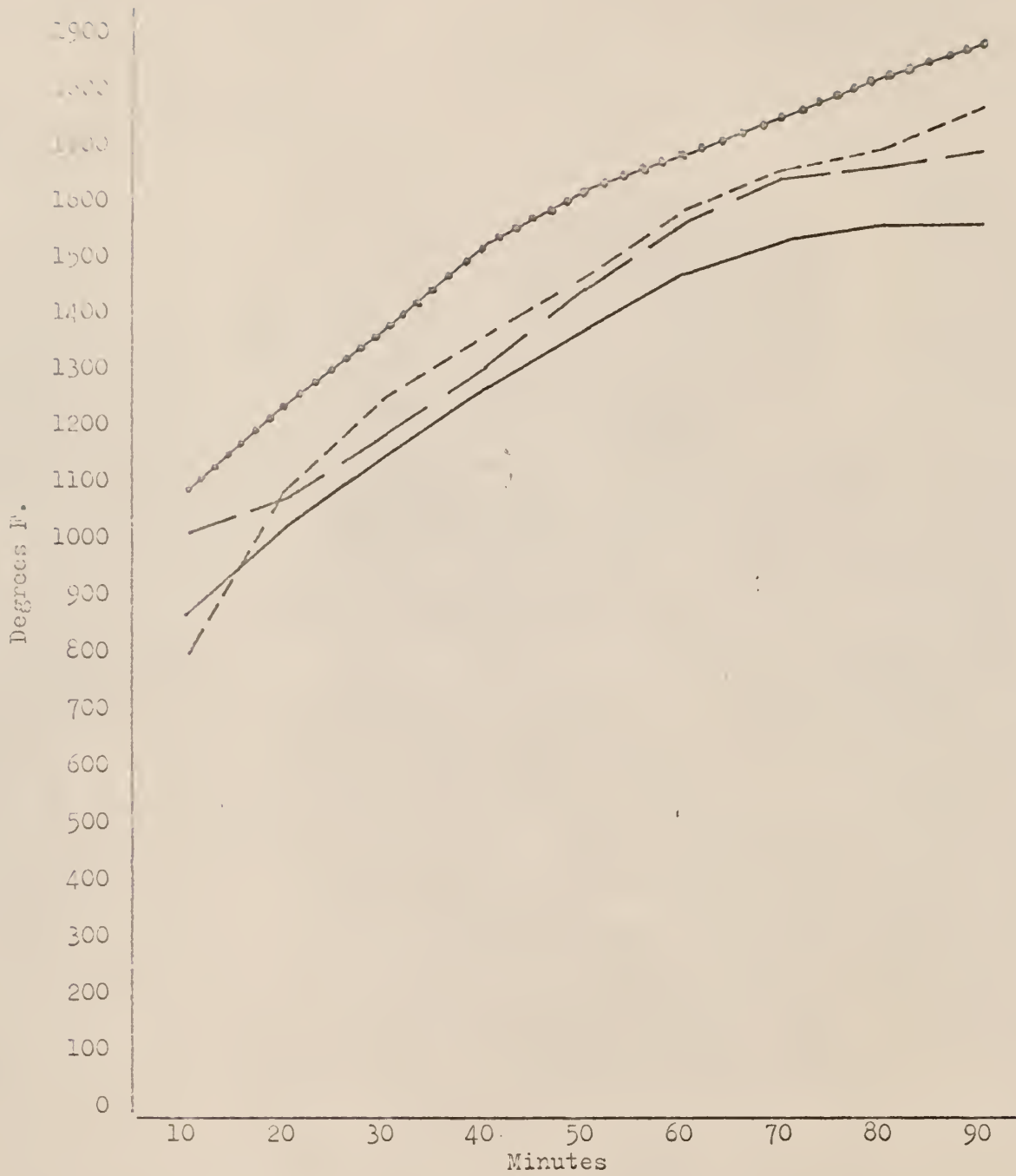
EXPLANATION OF GRAPH 1

This is meant to be a graphic presentation of the effects of the excessive reduction on temperature gain which was experienced early in the problem, and of kiln response, in terms of temperature increase, when the reduction had been eliminated.

The graph of Kiln 1 indicates that approximately 1560°F. was apparently the maximum temperature attainable from the combination of 20 pounds gas pressure and a flue of 1" by $4\frac{1}{2}"$, as indicated in Table 1. Kiln 2, although firing with a flame under only about one-third as much gas pressure (Table 1), achieved approximately 1700°F. in the ninety minutes allowed as maximum time for glaze melting. The observation that Kiln 2 fired 140° hotter with only one-third the fuel pressure as used in Kiln 1 gave dimension to the intensity of the reduction, and prompted a search in another direction for the solution of the reduction problem.

While Kilns 1 and 2 were experiments in changing the fuel pressures while keeping the flue size constant, Kilns 3 and 4 utilized flue variations and constant fuel pressures. With gas pressure set at 20 pounds and the flue tripled in cross sectional area (Table 1), it became apparent in examining the graph line of the firing of the third kiln that an increase in draft was having a greater effect on performance than changing gas pressure in firing Kiln 2. Increasing the flue size in Kiln 3, thus increasing the draft, marked the first time in the investigation that 1750°F. had been achieved, and passed, within the allotted ninety minute period. Seeking to obtain yet a higher temperature by further strengthening the draft, the four brick chimney (Plate XI, Fig. 2) was added to the design of Kiln 4. It will be noted that 1750°F. was passed at the seventy minute point, and that 1880°F. was achieved at the end of the ninety minute period.

Graph 1



— = #1
- - = #2
- - = #3
○ = #4

57

its construction were similar to the previous kiln with firebox underneath the kiln floor. Plate XII, Figure 1 is a view of the kiln's base and is typical of the type used under all the kilns tested. Plate XII, Figure 2 shows the joint and end support arrangement devised to span the firebox. Plate XIII, Figure 1 shows, in addition to a view of the completed kiln floor, the beveled corners in the fireport intended to permit the flame to be deflected to the kiln's front corners by forcing it off the two deflector bricks. Placement of these deflectors proved to be critical to successful firing and best results were obtained with a space of $\frac{1}{2}$ " for the flame to pass through. Less than that space resulted in a much hotter front section inside the kiln; more than $\frac{1}{2}$ " between allowed too much flame to pass through causing the rear section to be too hot with respect to the front. Night observation when action of the flames could be clearly seen, indicated that the small pieces of bricks used to support joints in the kiln floor aided in diffusing the burner flame. The 9" x 11" cover was incorporated into this design by overlapping the upper two courses of the kiln walls over the interior. Plate XIII, Figure 2 shows the application.

The first firing yielded these results: after ninety minutes, the temperature was 1800°F.; the average temperature gain for each five minute period was 98.6°F. Although the firing was begun with 20 psi gas pressure, it became necessary to increase the pressure first to 25 psi, and then to 30 psi. In terms of temperature rise, response to the gas pressure increases (particularly the increase to 30 psi) can be seen in Graph 2. Averages taken over the span of a number of firings: lid open time, 2.5 minutes; degrees lost, 158; recovery time, 23.2 minutes. In view of the kiln's performance within the required limits, no additional work was undertaken with the updraft kilns.

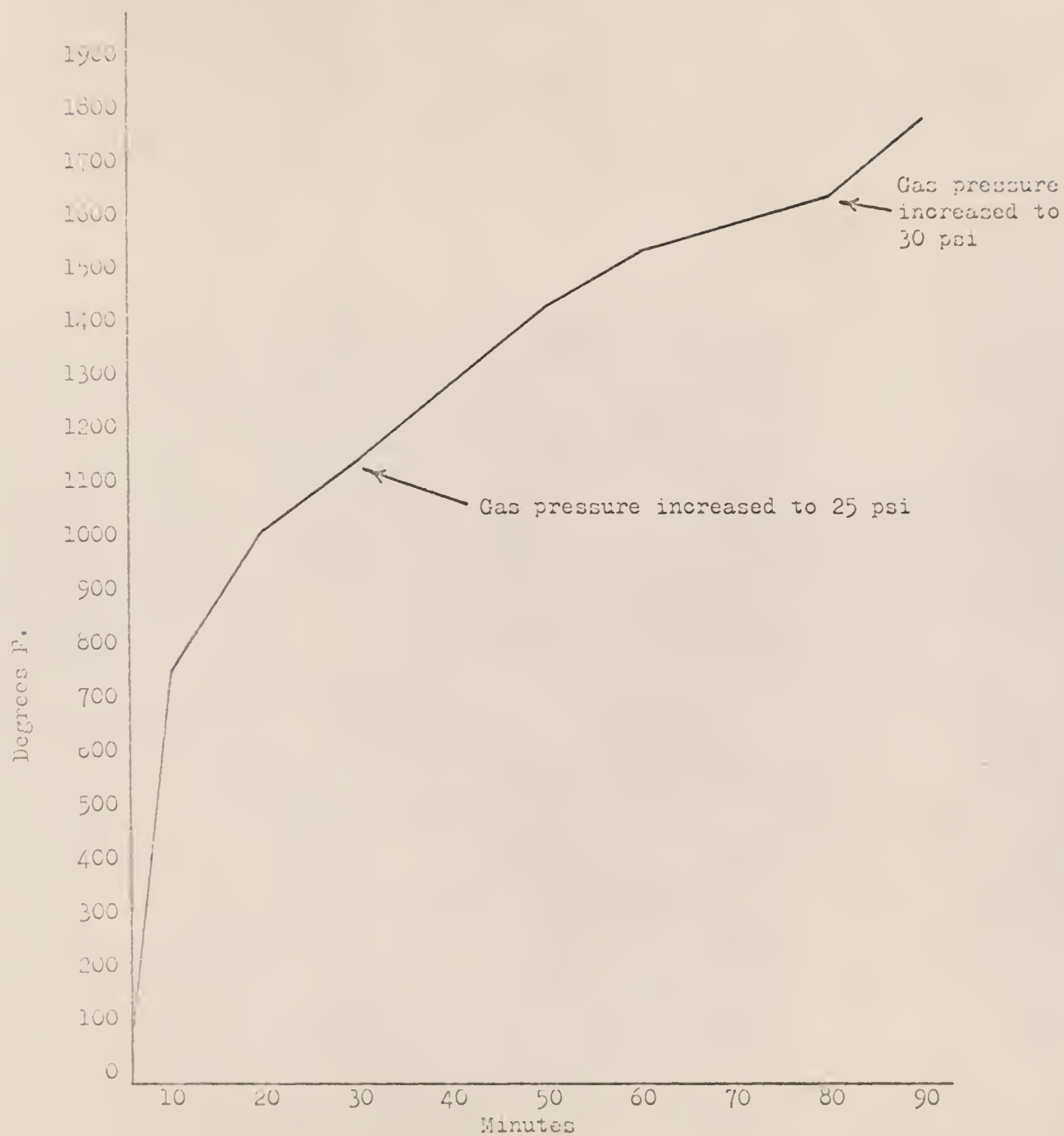
EXPLANATION OF GRAPH 2

After solving the reduction problem by strengthening the draft, as outlined in the explanation of Graph 1 and Table 1, it seemed that greater efficiency in the firings might be had by achieving better balance between the gas pressure and flue size by keeping the latter constant while varying the former, and attention was then turned in that direction.

Examination of the updraft performance line in Graph 2 will reveal that a change in fuel pressure from 20 pounds to 25 pounds made thirty minutes after the firing had commenced canceled the tendency for the rate of the temperature increase to slacken. The increase in pressure from 25 to 30 pounds at the eighty minute mark can be seen to have been beneficial to the extent that it caused a gain of more than $130^{\circ}\text{F}.$ during the next ten minutes. This 130 degree gain after the pressure advance compares to a gain of only about 50 degrees during the ten minutes prior to the pressure change.

This appears to be another reinforcement of the writer's allegation that an effective draft was one of the most critical, if not the most critical, of the characteristics of small kiln design as investigated by this problem. Were this not a correct deduction, it hardly seems likely that an increase in fuel pressure in the firing charted in this graph would have resulted in increase efficiency, when, in fact, the reverse was true in Kiln 1 of Table 1, when the fuel pressure was relatively high, and the flue area was relatively low.

Graph 2



EXPLANATION OF PLATE XII

- Figure 1. All the kilns were constructed on bases such as that illustrated here. The interior four and one-half bricks (here seen in lighter value) which served as the floor of the firebox were of the insulating type because of their superior heat reflecting and radiating properties.
- Figure 2. Increasing the width of the updraft kiln from 9" to $13\frac{1}{2}$ " brought the problem of supporting the joint caused by butting a full brick (9") against the half brick ($4\frac{1}{2}$ ") so as to prevent the collapse of the floor when the ware was placed into the kiln. This Figure shows how the thin pieces of brick were placed under the joints. In addition to supporting the joints, it is felt that they served to break up the flame from the burner and facilitate its passage through the floor into the kiln chamber.

PLATE XII



Figure 1



Figure 2

EXPLANATION OF PLATE XIII

- Figure 1. The flame entered the firebox between the two larger beveled pieces of brick. Upon striking the two small wedge-shaped pieces, it was broken up so that a portion went between, a portion to the right, and a portion to the left.
- Figure 2. By allowing the upper two courses of bricks to overhang the chamber area, it was found that the 9" x 11" lid which served the small downdraft could be utilized as the cover for this kiln also.



Figure 1



Figure 2

Downdraft Kiln Design and Firing Procedures

Attention was then given to downdraft kilns. In order that a performance comparison between updraft and downdraft designs could be made, it was decided that the volumes of the two downdraft kilns to be tested would remain the same as in the case of the two updraft versions reported in the preceding section.

A downdraft kiln depends, as does an updraft, on a rising flame, but in quite a different way. Rhodes explains:

The fire enters at the sides of the kiln and is deflected by a baffle wall which forces the hot gases to travel upward toward the top of the kiln. The flue is in the bottom of the kiln at the rear. The fire is drawn down . . . toward the flue. To force the fire downward in this way requires a lively draft or pull from the chimney. There are several distinct advantages to the downdraft kiln. The flames do not impinge directly on the ware, but strike the baffle wall first. The path of the flame is long, thus permitting a maximum of transfer of heat to the ware. The bottom of the kiln is heated not only by the passage of the fire through it, but by radiation. . . . Downdraft kilns have a tendency to be hot at the top
⁶⁴

The smaller kiln measuring 9" wide by $13\frac{1}{2}$ " deep by 10" high was tested first. Although the ware chambers of both the small updraft and the small downdraft were the same, it should be noted that there is a discrepancy of $4\frac{1}{2}$ " between the depth of the updraft (9") and the depth ($13\frac{1}{2}$ ") of the downdraft. This discrepancy was necessitated by the inclusion of the "baffle wall" (Plate XIV, Figure 1) which Rhodes refers to. This was meant to divert the flame up so that the top portion of the chamber would be heated, while allowing a part of the flame to pass below and to the sides of the deflector to heat the lower areas of the kiln.

The small kiln was built, as were they all, on a base of dense fire-bricks (Plate XII, Figure 1), and, again, the 9" by 11" cover was utilized.

⁶⁴Rhodes, op. cit., p. 200.

EXPLANATION OF PLATE XIV

- Figure 1. Because of the need to have the chamber of the down-draft identical to the updraft chamber for comparative purposes, it became necessary to increase the depth by $4\frac{1}{2}$ " in order to provide space inside the kiln, but outside the ware chamber area, for the flame deflecting brick.
- Figure 2. By adding a brick to the front and back of the lid used over the previous kilns, it was found that again the 9" x 11" lid could be used. Inasmuch as the lid now covered a downdraft kiln, the opening through the center of the lid was covered.

PLATE XIV



Figure 1



Figure 2

Plate XIV, Figure 2 indicates how the 11" lid was centered over the $13\frac{1}{2}$ " opening with bricks added in front and back as closures. The three openings illustrated in Plate XV, Figure 1 provided for flame passage from kiln to flue. Each space measured $1\frac{1}{4}$ " by $2\frac{1}{2}$ ", the spaces being equally divided across the back wall of the kiln. As the flames leave the kiln through the interstices and enter the flue, they are, of course, moving horizontally. To help turn the flames from the horizontal to the vertical, the beveled pieces of insulating brick shown in Plate XV, Figure 2 were incorporated at the back of the flue. The kiln was fired with and without these beveled pieces and performance was noticeably better when they were in place. This is attributed to a stronger draft due to less turbulence at the base of the flue since the flames were aided in their change of direction. Plate XVI, Figure 1 shows how the flue itself was constructed so as to be able to utilize the rear wall of the kiln for the front wall of the 9" by 4" flue. An efficient height was determined during firings by adding bricks to the flue and observing the reaction of the pyrometer. A height of $32\frac{1}{2}$ " above the kiln floor seemed to give the best results. When functioning properly, a low pitched roaring sound was heard in the flue. The finished kiln is illustrated in Plate XVI, Figure 2, and a typical firing is charted in Graph 3.

Using 20 psi gas pressure for all firings conducted in this kiln, the performance averages were: lid open time, 2.5 minutes; temperature lost, 277.5°F. ; recovery time, 17.5 minutes. Seventy minutes of firing time produced a temperature of 1970°F.

Furthering the comparison between updraft and downdraft kilns having the same volumes, a second downdraft was built and tested having interior dimensions of $13\frac{1}{2}$ " wide, 18" deep, and 15" high. The $4\frac{1}{2}$ " depth discrepancy was

EXPLANATION OF PLATE XV

- Figure 1. The three openings allow the spent flames to leave the kiln chamber and enter the flue from where they are exhausted into the outside air. In so doing, they cause a draft to pass through the kiln which promotes temperature rise.
- Figure 2. As the flames leave the chamber and enter the flue they must be turned from the horizontal to the vertical. The wedge shaped bricks were devised to aid the change of flame travel.

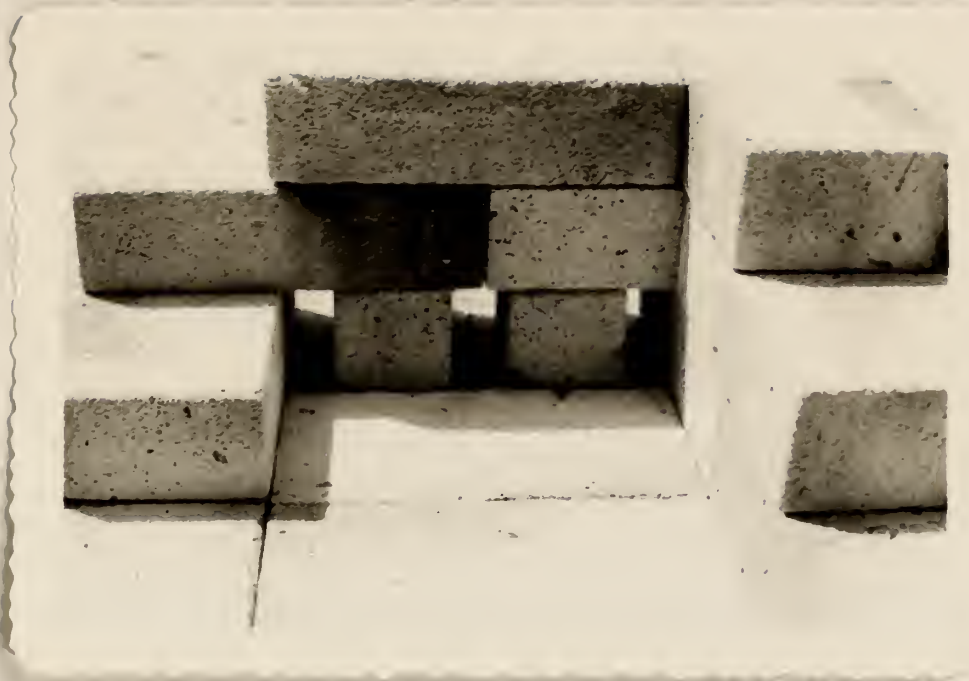


Figure 1



Figure 2



Figure 1

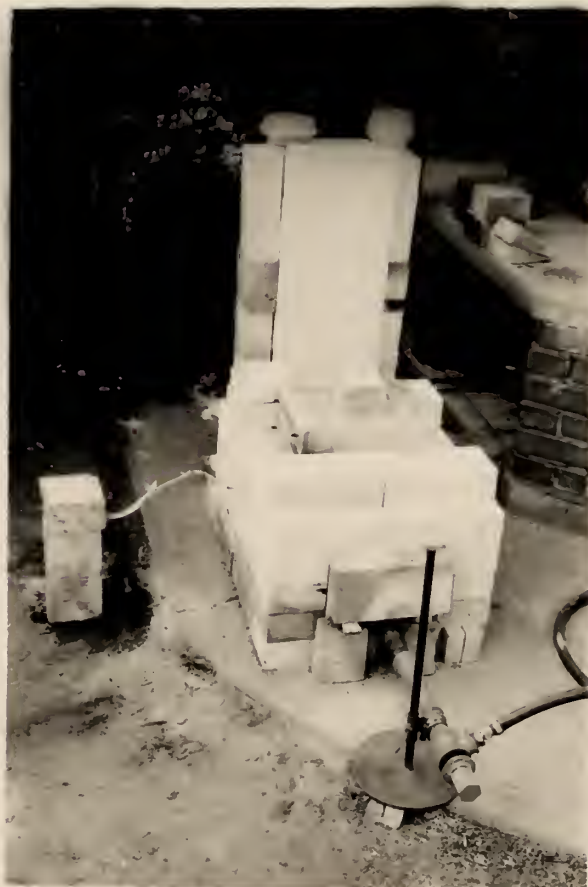


Figure 2

EXPLANATION OF PLATE XVI

Figure 1. Because of the mortarless nature of construction, a free standing flue did not seem feasible. To integrate the flue with the kiln for the sake of stability, and in order to use a minimum number of bricks, the rear wall of the kiln was made to serve as the front wall of the flue.

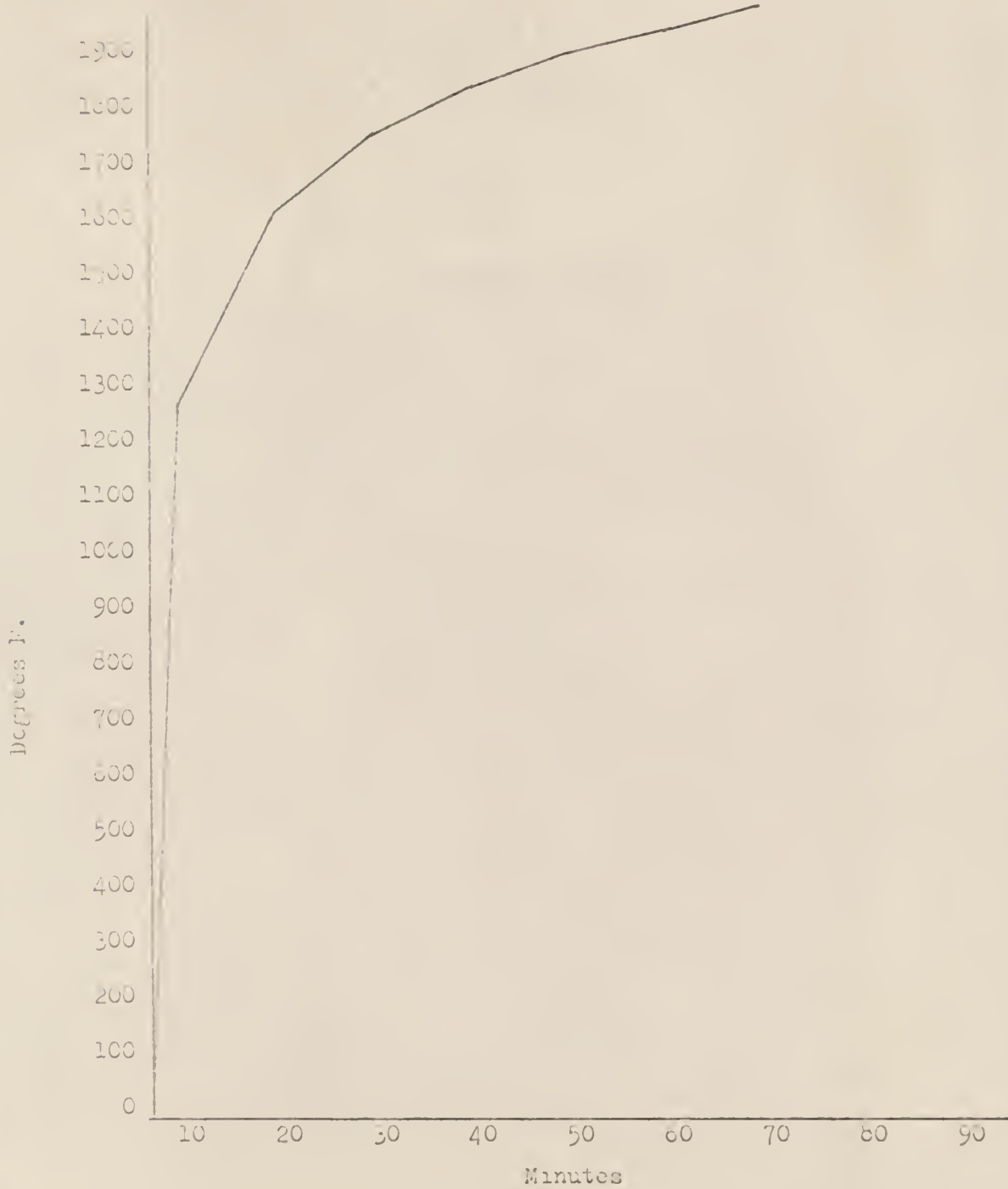
Figure 2. The completed $9\frac{1}{2}$ " x $13\frac{1}{2}$ " x 10" downdraft kiln is shown.

EXPLANATION OF GRAPH 3

The performance line of the small downdraft given in this graph seems to indicate, when compared to the performance line of the updraft in Graph 2, that the downdraft is the more efficient of the two designs. Efficiency is reflected not only in terms of temperature attained at the end of the firing period, but also in terms of conserving heat during the early stages of the firing. While the updraft presented in Graph 2 had risen to approximately 775 degrees after the first ten minutes of firing, the small downdraft had achieved 1250 degrees.

Although the updrafts attained glaze melting temperatures inside the criterion limit of ninety minutes, they did so more slowly than the downdrafts. The ability of the downdrafts to conserve more heat during the early stages of the firing is seen to be a definite advantage inasmuch as glaze melting commenced sooner, thus giving a longer time for the glaze melt to occur. This would seem to assure a more thoroughly melted glaze and a more intimate combination of glaze and coloring oxides.

Graph 3



present in this kiln for the same reason as in the previous downdraft. Plate XVII, Figure 1 shows how the deflecting brick, seen from the rear, occupies the front $4\frac{1}{2}$ " of the kiln making the usable volume $13\frac{1}{2}$ " x $13\frac{1}{2}$ " x 15". Seen in Plate XVII, Figure 2 are several construction features. The fireport arrangement as used on the updraft of similar volume was used in this kiln. The brick utilized to baffle the flames is of the dense firebrick. Its dimensions are $2\frac{1}{4}$ " x $2\frac{1}{2}$ " x 9" and is known as a "soap."⁶⁵ So that a portion of the entering flame could reach the lower areas just behind the deflector, the deflector brick was raised on five pieces of insulating brick measuring 1" x 1" x $2\frac{1}{2}$ ". This provided four, $1\frac{1}{8}$ " spaces through which the flame could pass. Also seen in Plate XVII, Figure 2 are the ports leading to the flue. Each space measured $1\frac{1}{2}$ " x $2\frac{1}{2}$ ". Illustrated in Plate XVIII, Figure 1, which is a view from the back looking toward the front through the passages just described, is the method employed to construct the flue. Height of the flue was determined experimentally by adding bricks during the first firing. Final flue dimensions were 14" wide, $4\frac{1}{2}$ " deep, and $40\frac{1}{2}$ " high. Flue construction is seen in Plate XVIII, Figure 2. The lid was made by compressing insulating bricks set on edge between two angle irons by tightening the bolts spanning from one angle iron to the other. Each section had two $\frac{1}{4}$ " rods piercing the bricks. These $\frac{1}{4}$ " rods were tightened against the angle irons and served to prevent sagging during the firings. While it functioned satisfactorily as a cover for the kiln, it proved too heavy for easy handling when the kiln was opened. The extra time required to remove and replace it resulted in excessive open time which caused serious heat loss. Plate XIX is a view of the completed kiln. The performance is presented in Graph 4. All

⁶⁵A. P. Green, Refractory Pocket Catalog, p. 94.

EXPLANATION OF PLATE XVII

- Figure 1. The greater width of the larger downdraft required a wider reflecting brick. Flame passage to the lower areas of the kiln was assured by the spaces provided beneath the brick.
- Figure 2. Essentially the same flue type was utilized here as in the small downdraft. The three flame escape ports are seen at the rear of the kiln.

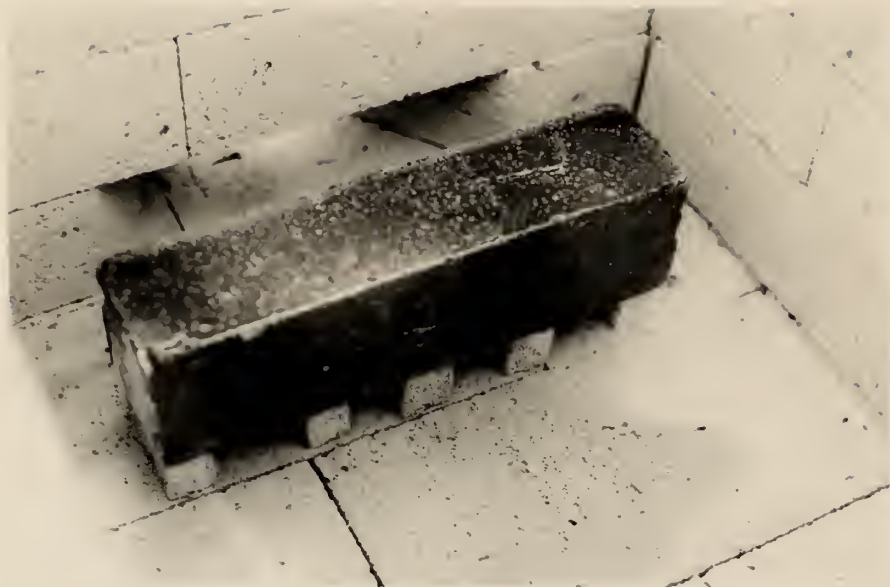


Figure 1



Figure 2

EXPLANATION OF PLATE XVIII

- Figure 1. A view into the flue from the back side shows details of flue construction and the three ports explained in Plate XVII, Figure 2.
- Figure 2. Flue construction employed in the largest downdraft kiln.



Figure 1

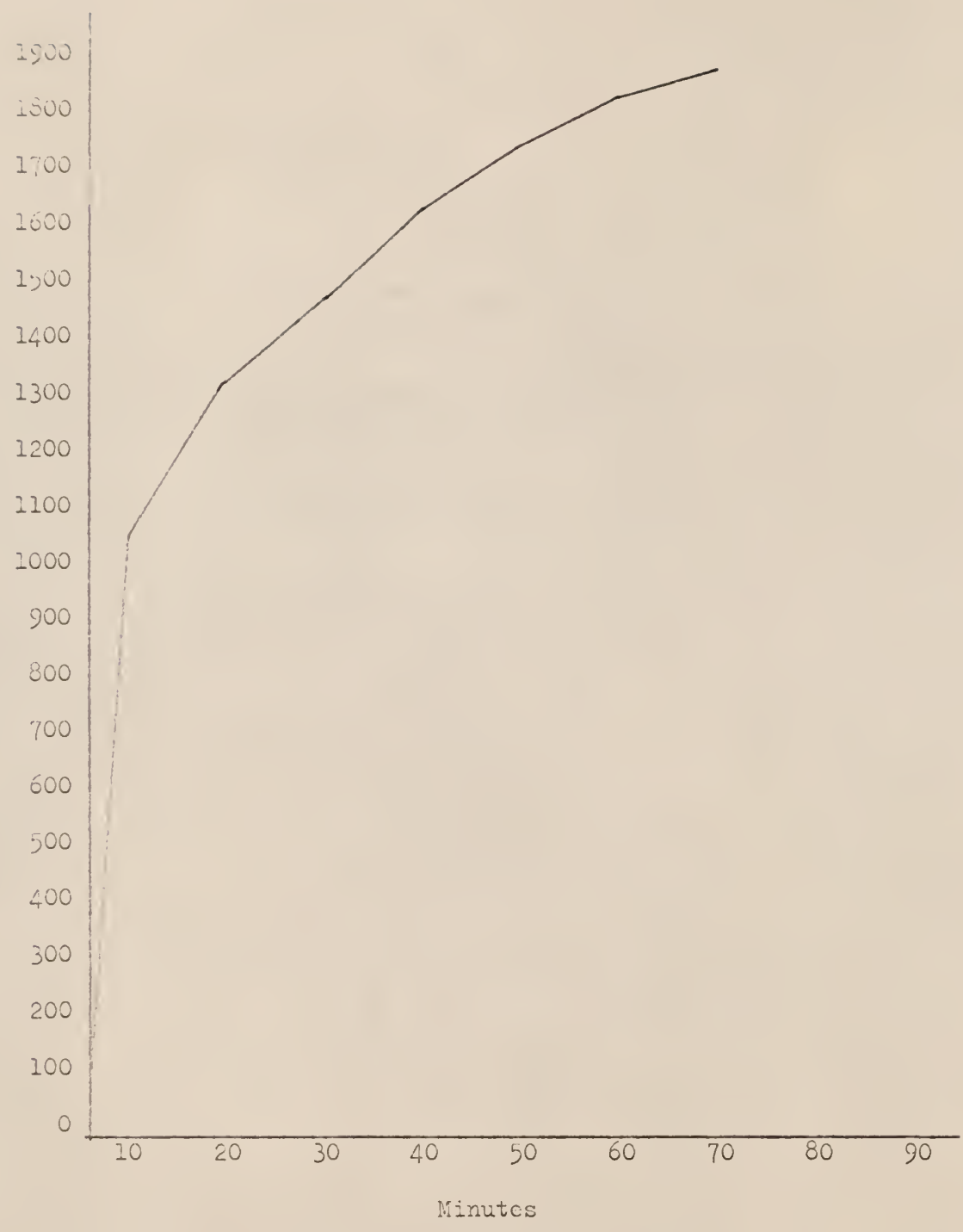


Figure 2

EXPLANATION OF GRAPH 4

Although the performance line of the largest downdraft graphed here does not rise as steeply as the line in Graph 3, it is, nevertheless, considerably steeper than the updraft given in Graph 2, seeming to reflect again the greater ability of the downdraft to conserve heat, particularly during the beginning phase of the firing.

Graph 4



firings yielded the following averaged data: lid open time, 5.1 minutes; temperature drop, 460°F ; recovery time, 32 minutes. The firing was started using a 20 psi pressure but was increased to 25 midway through the firing, and to 30 the last ten minutes. This schedule yielded 1880°F . in seventy minutes.

SUMMARY OF THE FIRINGS

Some judgment as to the success of the problem in terms of kiln performance can be made on the basis of the information presented in Table 2. The data representing the variable features of the kilns' performance, (Temperature After 90 Minutes, Average Temperature Increase Per 5 Minute Period, Average Lid-Open Time, Average Temperature Lost, and Recovery Time) was compiled from records kept during every firing for each kiln. The data given in each column of Table 2 expresses the averages taken of all the firings.

When the 9" by 9" by 10" updraft is compared to the downdraft of the same dimensions, it is immediately apparent that the downdraft is superior in the important categories of Temperature After 90 Minutes, Average Temperature increase per 5 Minute Period, and Average Recovery Time. It should be noted that the only area where the downdraft does not excel is in the Average Temperature Lost. However, in its ability to recover the temperature lost, the downdraft more than compensates, since it recovers more temperature in less time compared to the updraft.

Superiority for the larger downdraft over the larger updraft can be claimed only in two categories: Temperature After 90 Minutes, and Average Temperature Increase per 5 Minute Period. Not only does the downdraft lose more heat (nearly three times as much) as the updraft, but unlike the small downdraft, it requires nearly fifty percent longer than the comparable updraft to recover the lost temperature. The greater heat loss is attributed to the nearly two times longer period of Lid Open Time, and this longer time period seems attributable to the difficulty experienced in handling the large lid used to cover the larger downdraft kiln.

Perhaps the single most critical aspect of designing the kilns was

EXPLANATION OF TABLE 2

This is a tabulation of the various features of kiln designs and performances. The right hand five columns express averages which accrued over a number of firings.

While the information is largely self-explanatory, it should be noted that, except for the larger downdraft losing more temperature per lid opening and requiring more time to recover glaze melting temperature than the comparable updraft, the downdraft designs are clearly the superior kilns.

Table 2

kiln Type	Warc Chamber Dimensions (inches)	Volume in Cubic Feet	Flue Dimensions (inches) D - W - H *	Gas Pressure in Pounds Per Square Inch	Tempertaure After Ninety Minutes Firing	Average Temperature Increase Per 5 Min. Period	Average Lid Open Time (Minutes)	Average Temperature Lost Degrees F.	Average Recovery Time (Minutes)
Updraft	9 x 9 x 10	.47	3 x 4½ x 13½	20	1880°	104.3°	2.2	132°	19.7
Updraft	13½ x 13½ x 15	1.58	3 x 4½ x 13½	30	1800°	98.6°	2.5	158°	23.2
Downdraft	9 x 9 x 10	.47	9 x 4 x 32½	20	1970°	140.6°	2.5	277.5°	17.5
Downdraft	13½ x 13½ x 15	1.58	14 x 4½ x 40½	30	1880°	134.2°	5.1	460°	32.

* D = Depth
W = Width
H = Height

the function of the draft and the dependency of draft on a proper flue. In reviewing the experiences with the first updrafts, it can be said that no significant progress was made until the draft problem was solved by stacking the four bricks on end atop the lid (Plate XI, Figure 2), thus forming a short chimney. It was at this point that over reducing ceased to be a major problem. Having had the experience of observing the effect of draft on kiln performance, subsequent circulation problems were much easier to handle, resulting in reasonable performance from the kilns with less trial and error search for solutions.

Another factor which seemed to facilitate problem solving was the addition of the pressure regulator and pressure indicating gauge to the propane supply. This addition assured pressure uniformity throughout the firing and provided a means whereby the exact pressure of the gas supporting the flame could be ascertained at a glance.

Also critical to evaluating kiln design and performance, especially while the firings were in progress, was the addition of the pyrometer. As adjustments were made to the gas supply, burner orifice, flue configuration, etc., the effects were soon noted by the change of temperature indicated by the pyrometer. When the pyrometer was read periodically and the temperatures plotted against time, a performance profile resulted from which one could assess how certain adjustments were affecting the performance by the way in which the graphed line rose or fell.

The kilns, when judged against the four criteria established to govern their design and operation, seem to the writer to have been successful. In terms of portability, it can be said that all four kilns were easily assembled, dismantled and moved. When disassembled for cleaning and/or cleaning, repairs or modification, no problems, aside from an occasional broken brick were encountered. Moreover, on the occasions when a large pot required an enlarged chamber,

EXPLANATION OF PLATE XIX

This illustrates the finished 13 $\frac{1}{2}$ " x 18" x 15" down-draft kiln.



or when a load of small ware only partially filled the chamber, the proper chamber adjustments were quickly and simply made by adding or removing layers of bricks.

No difficulties were experienced relative to the acquisition of materials and equipment. Cylinders of propane, valves and gauges were available locally, as were the dense firebricks. Insulating firebricks and atmospheric burners had to be ordered from manufacturers, but presented no problems with availability or delivery. In terms of material costs, the dense firebricks were approximately 25¢ each, while the insulating type were nearly 32¢ each. Between seventy one and seventy two hours of firing were entailed in the problem with an approximate cost of 22¢ per hour.

While a kiln chamber of less than two cubic feet may seem too small for most kinds of firing, it is felt that the chambers were sufficient in all but rare cases, both in terms of accommodating the ware and in the promotion of efficient firing. When the chamber did prove to be too small to receive a large form, the kiln was easily enlarged. Determining to govern the horizontal dimensions by the $4\frac{1}{2}$ " module seemed to hold brick waste to a minimum, inasmuch as walls could be constructed with only full bricks and half bricks. It is speculated that the rather favorable average of recovery times given in Table 2 was an advantage accruing from the small chamber sizes since they present less wall area and less volume to be heated than do larger kilns. This would seem to reinforce the initial decision to limit the volumes to less than two cubic feet.

After the problem of excessive reduction was overcome in the updraft segment of the problem, the firing time criterion was met without undue difficulty. Table 2 indicates that both downdrafts, as well as the small updraft passed the upper limit of 1800°F. required by the fourth criterion in the ninety minute period, and that the large updraft attained 1800°F. at the ninety minute

mark.

Inasmuch as designing and firing kilns at the level of the studio potter is something less than a science, sometimes depending upon the intuitive or empirical approach, the writer feels that the summation should also include a few words addressed to what seems to him to be the value of the practical experience accruing from a problem such as the one this paper seeks to report. It seems that having opportunity to learn to judge kiln temperature from the color of the interior, or to evaluate the character of the interior atmosphere by the condition of the flames issuing from the flue, or to determine how well the kiln is firing from the sound of the draft in the flue are all worthwhile aspects of the problem, and represent a gain to the writer in the terms of practical experiences. Admittedly intangible and impossible to evaluate in concrete terms, they nevertheless seem to constitute a valid part of the learning process.

In view of having satisfied the criteria, and in view of the way in which the kilns have functioned during the many firings held after completion of the research, the writer feels justified in asserting that the problem has been successfully concluded.

THESIS POTTERY

Presentation of the following photographs is meant to be representative of the writer's work with clay, as well as to provide a visual record of the quality of the glaze melting which was accomplished by the kilns that grew out of the data collected during the research firing phase of the problem. While some of the pots were fired in updraft kilns, and others were fired in the downdrafts, the glaze quality apparently remained the same.

EXPLANATION OF PLATE XX

- Figure 1. The hand-built bottle, after being glazed with an off-white glaze, was sprayed with red copper oxide.
(Ca. 3" W. x 7" H.)
- Figure 2. The vertical indentations were made before the pot came from the wheel by striking the surface lightly with the edge of a thin stick. The small rondel was stamped into the wet clay. Color resulted from brushing manganese dioxide on the pot before glazing.
(Ca. $3\frac{1}{2}$ " W. x $3\frac{1}{2}$ " H.)



Figure 1



Figure 2

EXPLANATION OF PLATE XXI

Figure 1. Wheel formed, the linear pattern was applied by training a copper-bearing slip from a small bulb syringe. During the firing, the slip melted through the white overglaze to provide the contrasting pattern.
(Ca. 4" W. x 4½" H.)

Figure 2. Handformed by rolling the clay into a thin, flat, slab. The two surfaces of the seam were fused by pressing a textural stamp into the soft clay. Although only white glaze was used, enough carbon from the smoking period impregnated the slightly under-fired glaze to yield the dark areas seen on the surface.
(Ca. 3" W. x 7½" H.)



Figure 1



Figure 2

EXPLANATION OF PLATE XXII

- Figure 1. The line pattern was carved into the surface of the leather-hard clay while the pot was rotating on the wheel. Copper-bearing slip was brushed into the incised areas and influenced the color of the glaze. (Ca. 4" W. x 7" H.)
- Figure 2. The dark areas of this small bottle were covered with a glaze containing copper and cobalt. The form was then completely dipped in the white glaze seen about the neck. The two glazes interacted during the melt to produce a variegated surface. (Ca. 3" W. x 4" H.)



Figure 1



Figure 2

EXPLANATION OF PLATE XXIII

- Figure 1. The body of this small, closed form was wheel-thrown and the neck was added later by fusing a coil of clay to the top. The color resulted from training a dark blue glaze under the white glaze and relying on fusion of the two to provide a pattern of soft contrast.
(Ca. 3" W. x 4" H.)
- Figure 2. Somewhat larger than most of the pottery presented here, the pot was thrown, textured, while soft, with a fork, colored in the dark areas with the copper slip, and over-glazed with a white glaze.
(Ca. 12" W. x 14" H.)



Figure 1



Figure 2

EXPLANATION OF PLATE XXIV

- Figure 1. The dark areas were scratched through the white glaze and then filled in with a copper-cobalt glaze which darkened during the smoking period to provide the strong contrast.
(Ca. $4\frac{1}{2}$ " W. x 7" H.)
- Figure 2. The dark areas seen on this pot resulted from the copper slip combining with the white glaze. The neck was freely thrown, and the small textured area was done by pressing a button of clay onto the soft pot.
(Ca. 4" W. x $5\frac{1}{2}$ " H.)



Figure 1



Figure 2

EXPLANATION OF PLATE XXV

- Figure 1. Formed by hand from a thin slab of clay, the bottle was covered overall with a white glaze. The dark rim resulted from brushing copper carbonate over the glaze.
(Ca. $4\frac{1}{2}$ " W. x $6\frac{1}{2}$ " H.)
- Figure 2. The bowl was freely thrown and footed by adding coils of clay after the upper area was leather-hard. The area of rim texture was pressed into the clay while soft, and the color was gotten from copper slip applied under the white glaze.
(Ca. 12" W. x $10\frac{1}{2}$ " H.)

PLATE XXV



Figure 1



Figure 2

EXPLANATION OF PLATE XXVI

- Figure 1. The lineal pattern was obtained by trailing a black glaze over the white glaze.
(Ca. $4\frac{1}{2}$ " W. x $3\frac{1}{2}$ " H.)
- Figure 2. After the white glaze was applied to the interior, the same glaze was trailed in the pattern seen on the outside and covered with wax. When the dark blue glaze of the outside was applied, it was repelled by the wax, and a strong contrast resulted.



Figure 1



Figure 2

EXPLANATION OF PLATE XXVII

- Figure 1. Color on this wheel-thrown bowl resulted from slip brushed into the pattern of the lowered areas. The network of crazing was encouraged by rapidly cooling the pot after the smoking and then returning it to the smoke so that carbon could darken the cracks.
(Ca. 10"W. x 7" H.)
- Figure 2. Dark areas on this bottle result from twice dipping in the copper glaze followed by a complete covering of white glaze.
(Ca. 3" W. x 6½" H.)

PLATE XXVII



Figure 1



Figure 2

EXPLANATION OF PLATE XXVIII

- Figure 1. The brushwork was done in copper carbonate under the white glaze.
(Ca. $3\frac{1}{2}$ " W. x 8 " H.)
- Figure 2. This bottle form was made on the wheel. Copper slip was brushed on the pot while it was revolving slowly on the wheel. The crazed network was formed by rapid cooling.
(Ca. 9" W. x 12" H.)



Figure 1



Figure 2

BIBLIOGRAPHY

- Binyon, Laurence. The Spirit of Man in Asian Art. New York: Dover Pub. Inc., 1965.
- Goemaraswamy, Ananda. Buddha and the Gospel of Buddhism. New York: University Books, 1964.
- Cox, Warren E. The Book of Pottery and Porcelain. New York: Crown Pub. Co. Inc., 1964.
- Creel, Herrlee G. Chinese Thought. Chicago: University of Chicago Press, 1953.
- Creel, Herrlee G. Confucius and the Chinese Way. New York: Harper and Row, 1949.
- "Eclipse Atmospheric Burners," Bulletin E-1. Rockford, Illinois: Eclipse Fuel Engineering Company.
- Fenclosa, Ernest F. Epochs of Chinese and Japanese Art. Vol. 1. New York: Dover Pub. Inc., 1963.
- Fenclosa, Ernest F. Epochs of Chinese and Japanese Art. Vol. 2. New York: Dover Pub. Inc., 1963.
- Gard, Richard A. Buddhism. New York: George Braziller Co., 1962.
- Garzio, Angelo C. "Raku," Ceramics Monthly, Vol. 15, No. 6. (June, 1967), 19-26.
- Garzio, Angelo C. Reference Outline for Beginning Ceramics. Manhattan: Kansas State University Press.
- Graham, Hazel H. Japanese and Oriental Pottery. Yokohama: Yamagata, 1957.
- Humphreys, Christmas. Buddhism. Baltimore: Penguin Books Inc., 1962.
- Leach, Bernard. A Potter's Book. London: Faber and Faber, 1940.
- Munsterberg, Hugo. The Ceramic Art of Japan. Rutland, Vermont: C. E. Tuttle and Co., 1964.
- Nelson, Glenn C. Ceramics. A Potter's Handbook. New York: Holt, Rinehart, Winston, 1966.
- Nineteenth Wichita National Decorative Arts and Ceramics Exhibition Catalog. Wichita, Kansas: Wichita Art Association. 1966.
- Okamura, Rakuso. The Book of Tea. New York: Dover Pub. Inc., 1964.
- Refinery Pocket Catalog. Mexico, Missouri: A. P. Green Firebrick Co.
- Rodes, Daniel. Clay and Glass for the Potter. New York: Greenberg, 1957.

Rhodes, Daniel. "Twenty-third Ceramic National," Crafts Horizons. XXV, No. 1.
(January, February), 18-23.

Rhodes, Daniel. Stoneware Porcelain: The Art of High-Fired Pottery. Philadelphia: Chilton Company, 1959.

Soldner, Paul. Kiln Construction. New York: American Craftsmen's Council, 1965.

Soldner, Paul. "Workshop: A Kiln is Built," Crafts Horizons. XXV, No. 1.
(January, February), 38-39.

Swann, Peter C. Art of China, Korea, and Japan. New York: Praeger Inc., 1963.

Twenty-fourth Ceramic National Ceramic Exhibition Catalog. Syracuse, New York:
Everson Museum of Art. 1967.

Willets, William. Chinese Art. Vol. II. Baltimore: Penguin Books Inc., 1958.

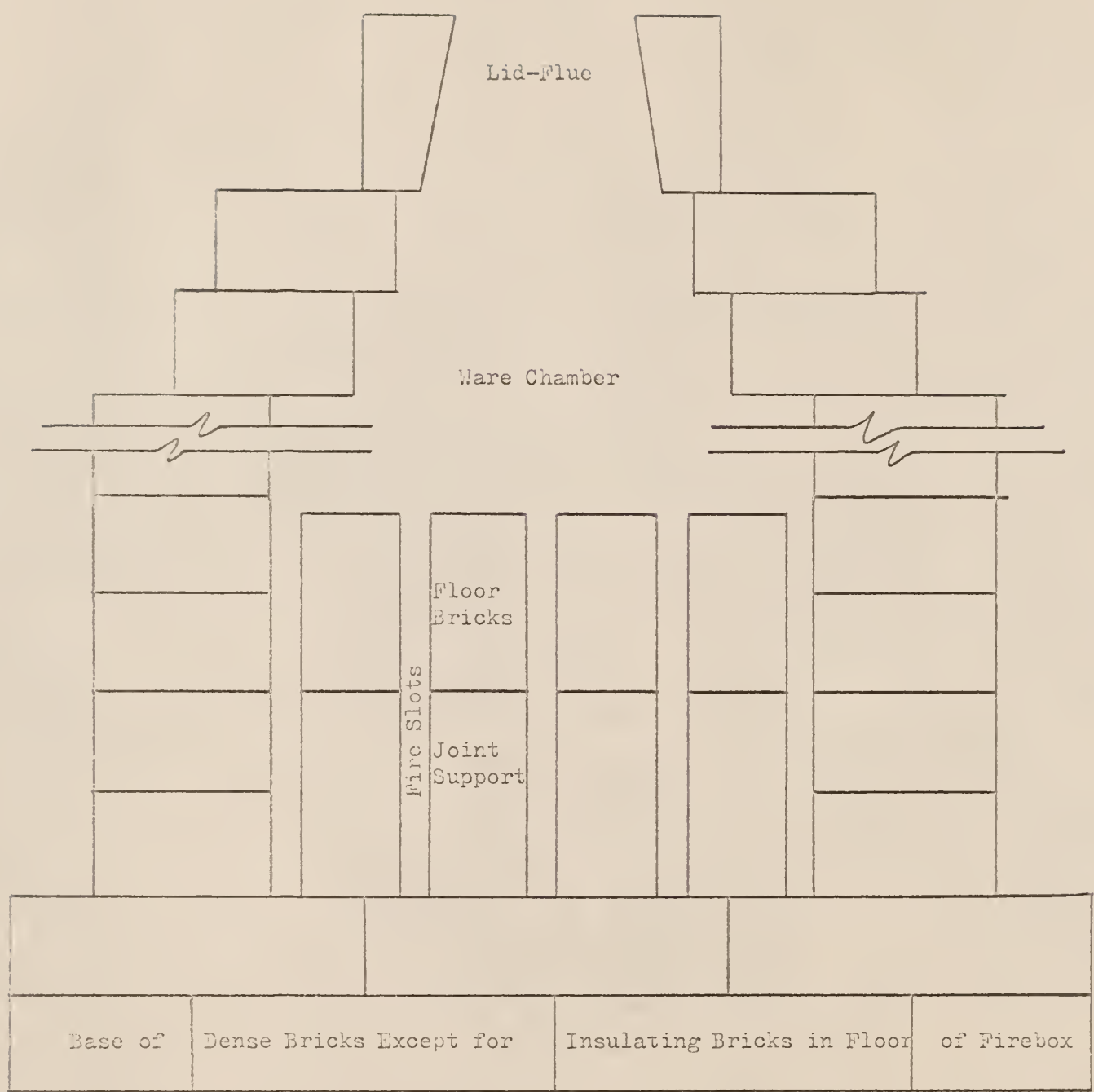
APPENDIX

KILN PLANS

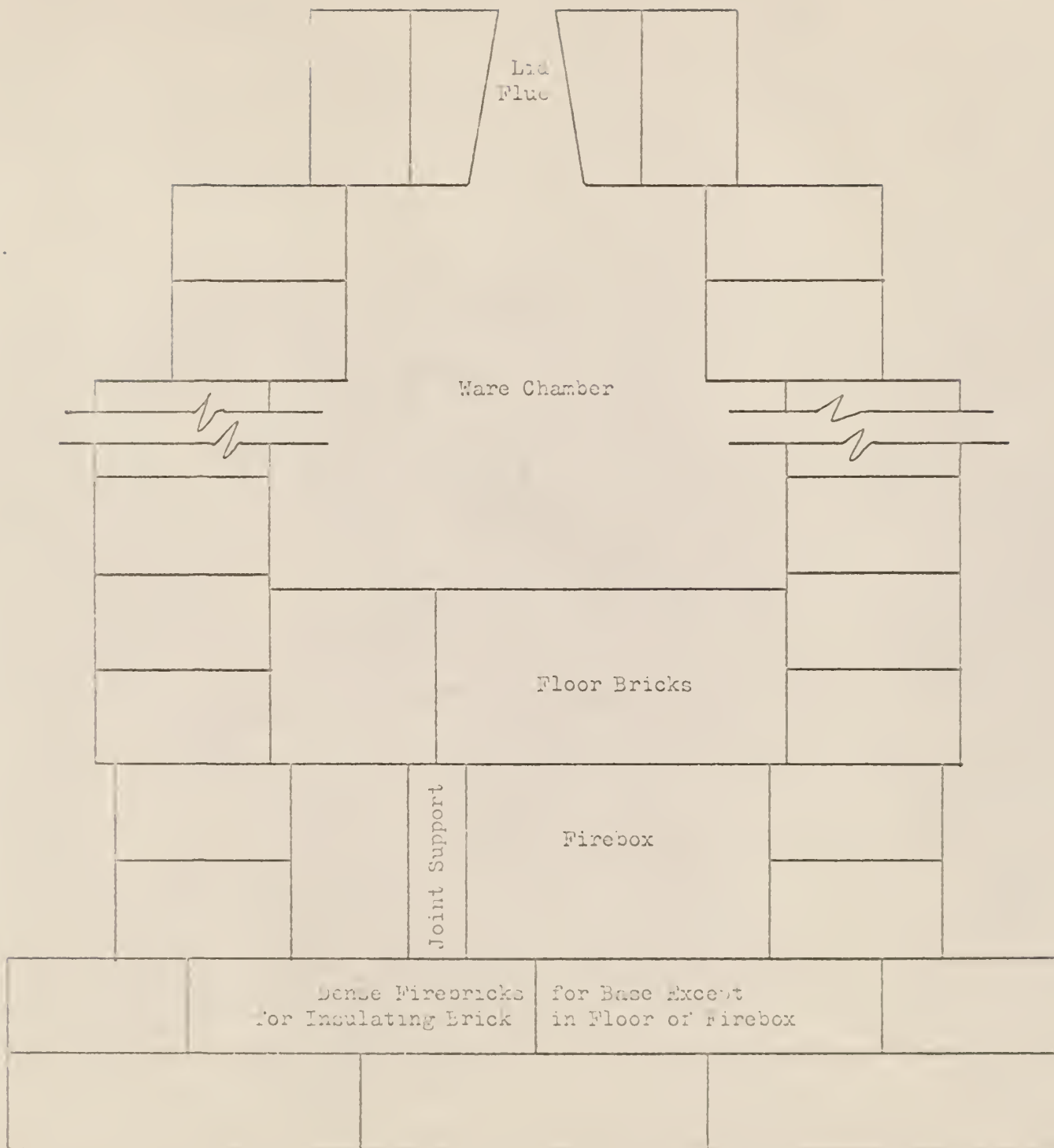
The kiln plans should be regarded as adjuncts to the explanations given in the body of the thesis. Interpretation will depend upon reference to some of the photographs and written descriptions given in the text.

Plan A refers to the larger of the two updrafts ($13\frac{1}{2}"$ x $13\frac{1}{2}"$ x 15"), while the features of the larger downdraft ($13\frac{1}{2}"$ x 18" x 15") are given in Plan B.

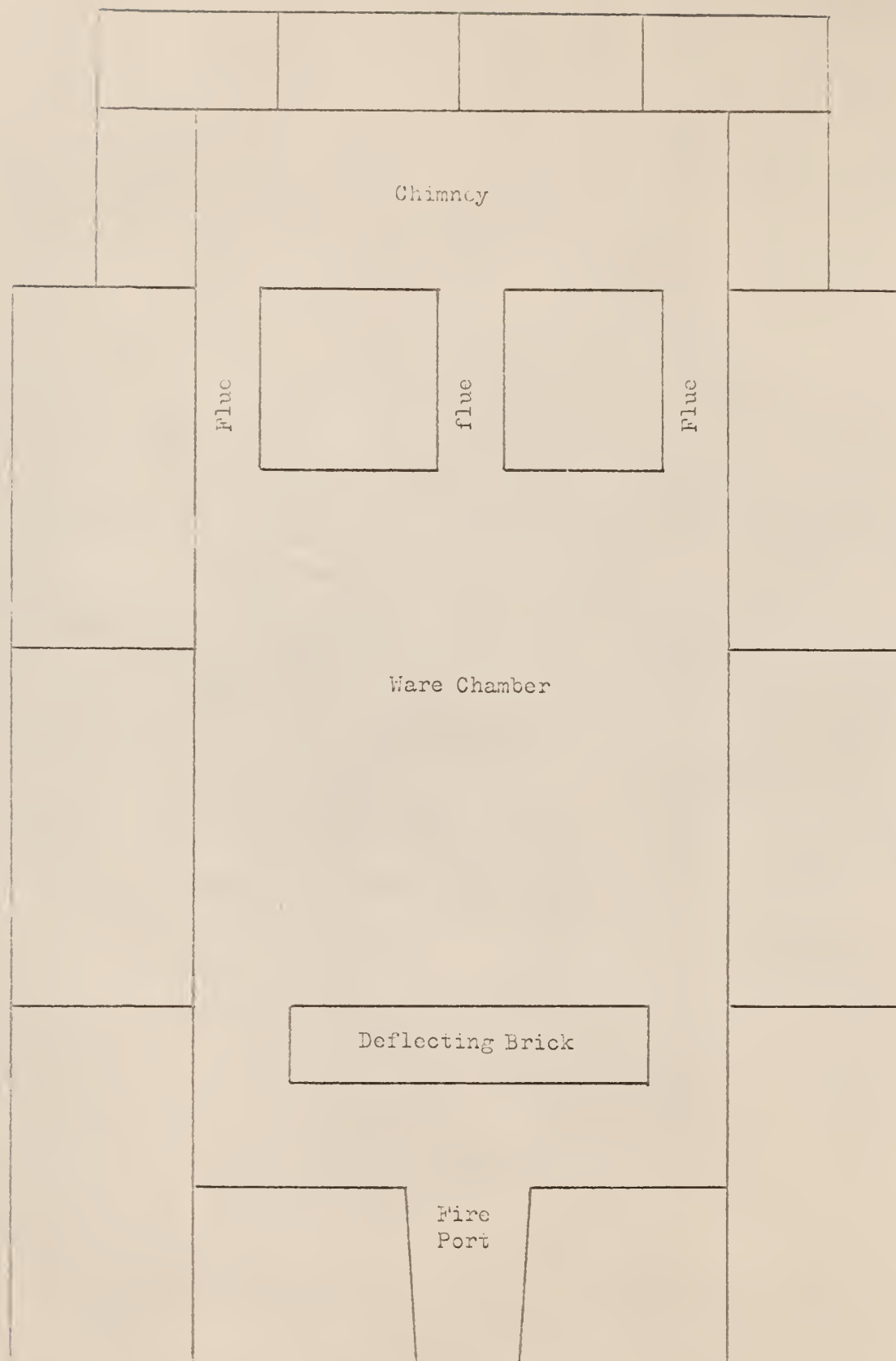
In view of the modules governing construction ($4\frac{1}{2}"$ horizontally, $2\frac{1}{2}"$ vertically), which would seem to make for relatively easy interpretation of the plans, it was decided not to include dimensions in the drawings. The scale used in preparing the plans was: 3 inches equals one foot.



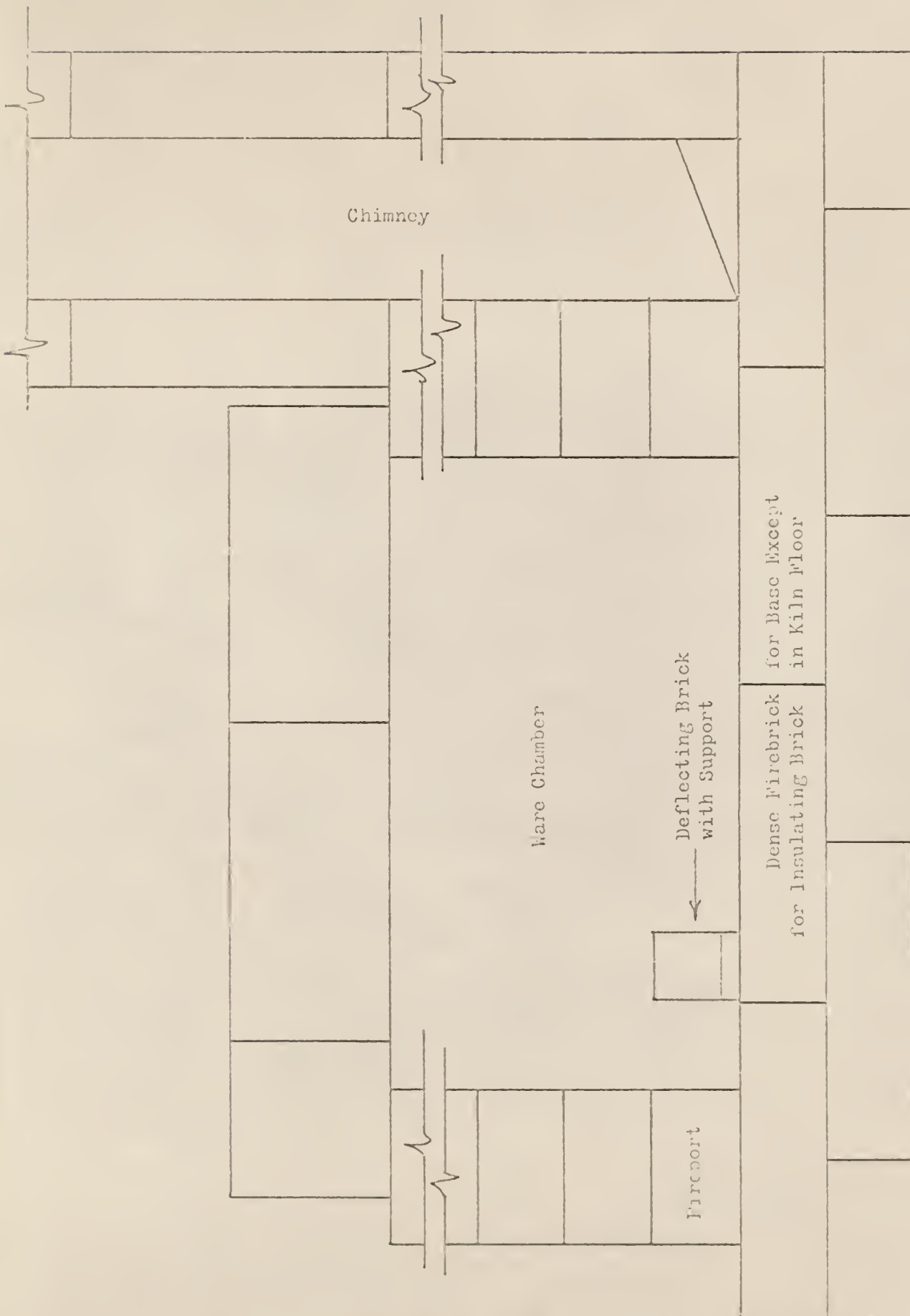
Kiln A Longitudinal Section Scale: 3" = 1'- 0"



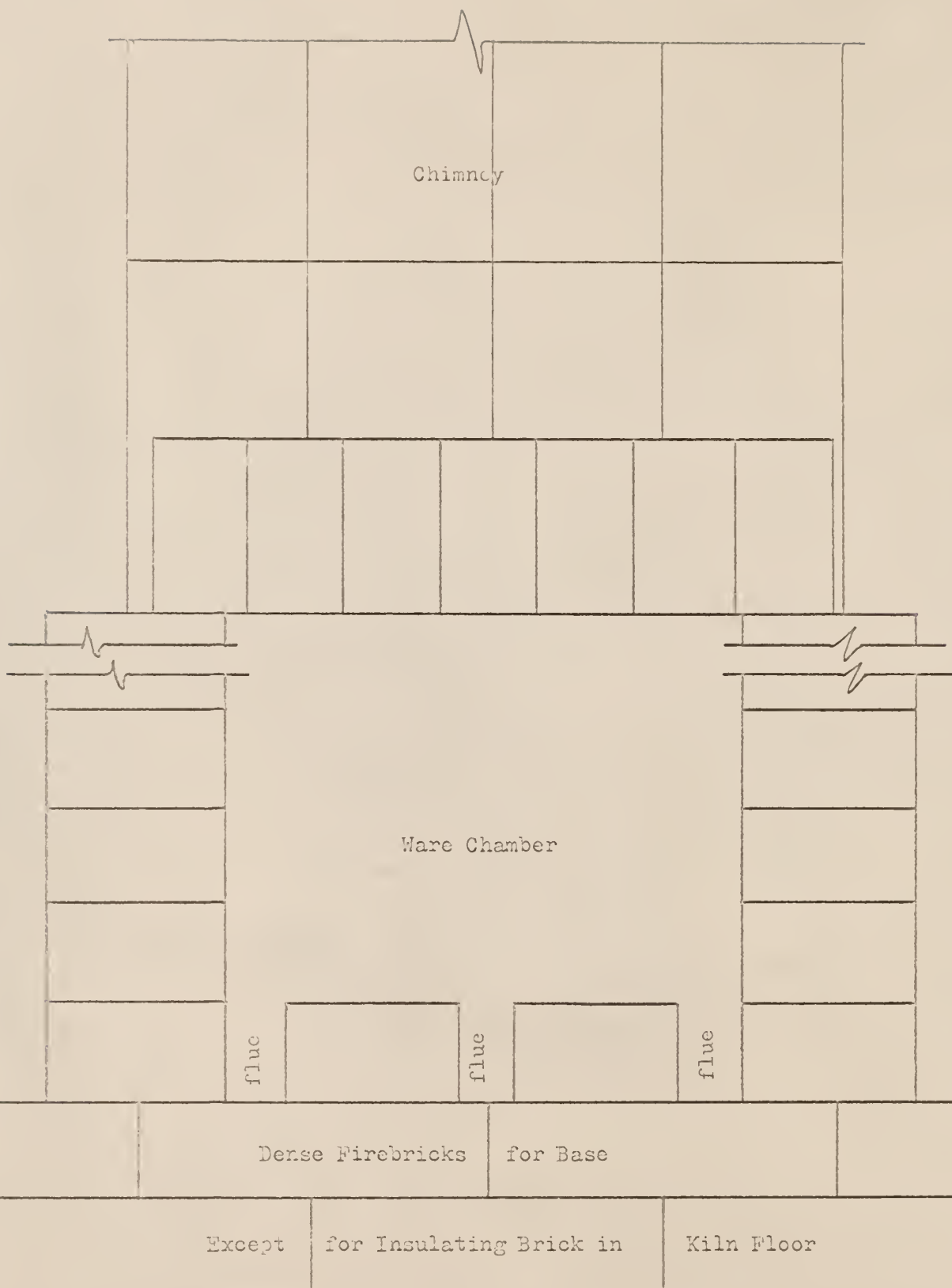
Plan A Transverse Section Scale: 3" = 1'- 0"



Kiln B Plan Scale: 3" = 1' - 0"



Kiln D Longitudinal Section Scale: 3" = 1'-0"



Kiln B. Transverse Section Scale: 3" = 1'-0"

AN INVESTIGATION OF THE CHARACTERISTICS
OF SMALL, GAS FIRED RAKU KILNS

by

RAYMOND KAHMEYER

B. A., Kansas State University, 1963

An Abstract

of

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF ARTS

Department of Art

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1968

The thesis grew out of the writer's regard for the Japanese Raku pottery and the processes by which it is made and fired, and represents an attempt to accumulate data from which several kilns suitable for Raku firing could be developed.

The tradition of Raku is rich and long, having originated in Japan during the sixteenth century as an adjunct to the Zen-Buddhist ceremony of tea. The tea ceremony, called cha-no-yu by the Japanese, symbolized the Zen concepts of simplicity, austerity and restraint, and initially utilized the simple, unassuming rice bowls of Korean peasants. Under the auspices of the shogun Rikyu, an arbiter of taste in the tea ceremony of sixteenth century Japan, the potter Chojiro began to produce ware expressly for the ceremony. Thus was begun a tradition which is currently influential in American ceramics.

After reviewing the history of Raku, the thesis continues with a presentation of the objectives of research, research techniques, results, and conclusions expressed in working drawings for two kilns.

Successful performance of the kilns to be evolved was judged to be dependent upon the following criteria:

1. Portability. Because the Raku process is best suited to an outdoor environment, it was felt that, if the kilns were entirely portable, they would be more serviceable. Portability was achieved largely because of the mortarless construction which facilitates assembling and dismantling. Propane gas in moveable cylinders was selected to fuel the kilns, thus making the fuel supply equally as portable as the kilns.
2. Accessibility of Materials. The writer felt that, if the kilns were to have practical application, the materials required for their construction would have to be readily available at a

reasonable cost. Consequently, all components were selected from standard sources which are listed in the thesis.

3. Firing Chamber Dimensions. In order to facilitate a rapid temperature rise, the chambers were not allowed to exceed four cubic feet. So as to preclude complicated assembling and dismantling procedures, plus minimizing brick waste, all dimensions were based upon the standard two and one half by four and one half by nine inch kiln brick. Thus, the horizontal dimensions were controlled by a four and one half inch module while the vertical measurements were based upon a module of two and one half inches.
4. Firing Time. In the interest of efficiency, ninety minutes of firing time was allowed for the kilns to reach the 1750 degree Fahrenheit temperature required to melt the glaze.

The kilns, judged by the foregoing criteria, as well as by their performance during many firings subsequent to the period of research, seem to be successful and adequately suited to the needs of the Raku potter.